UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1022

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ February 3, 1922

RELATION OF INITIAL TEMPERATURE TO PRESSURE, VACUUM, AND TEMPERATURE CHANGES IN THE CONTAINER DURING CANNING OPERATIONS

By

C. A. MAGOON and C. W. CULPEPPER
Office of Horticultural and Pomological Investigations

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

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CONTENTS.

CANNING PROBLEMS.

If canned foods of uniform quality are to be produced, the various canning operations must be placed upon a sound scientific basis and the methods which are employed, so far as the nature of the food substance will permit, must be carefully standardized. The situation calls for the elimination of the element of chance and the abandonment of "rule-of-thumb" practices. It is equally important that those factors which affect the cooking or processing of the food after the can is sealed should be thoroughly understood. To throw further light upon the matter of initial temperatures and their bearing upon pressures, vacuums, and temperature changes during and following the processing period, the present work was undertaken, and it is hoped that the data presented herewith will contribute to the solution of some of the canning problems.

REVIEW OF THE LITERATURE.

In an earlier paper the writers (8)[1] presented the results of preliminary studies upon the fundamental factors affecting temperature

[1] Serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

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changes in foods during canning, but a detailed consideration of the important influence which initial temperatures have upon the form of the heat-penetration curves and their bearing upon sterilization processes was reserved until initial temperatures could be taken up in their proper relations with exhaust, pressure, and vacuum.

Since the above-mentioned paper was submitted for publication two further contributions have been made. The first of these, by Thompson (9), enters into a discussion of the theoretical application of physical laws to canning procedures. In addition to the consideration of the general phases of the subject and a study of the diffusivity constant "K" dealt with in his original paper, this author gives valuable formulas for calculating the approximate time-temperature curves for cans of food when processed at different retort temperatures, other factors being the same, and also for calculating the curves for different sizes of cans when processed under like conditions.

Thompson's study of the time-temperature curves for cooling, however, suggests that such curves might be calculated directly from the heating curves, inasmuch as reversing the temperature conditions of the water bath from hot to cold should result in a curve of the same form as the heating curve. That this can hardly be the case with foods will readily be seen. The viscosity of the liquor varies with the temperature. Except where heat brings about a change in the colloidal substances, the heating curve is always a record of a change from a more to a less viscous condition, while in cooling, without exception, the change is from a less to a more viscous condition. The curves will not be the same, as in this case the final portion of the heating curve will be steeper than the corresponding part of the cooling curve. Furthermore, during processing permanent physical changes which alter greatly the rate of heat transfer within the container commonly occur in food substances; hence, even the rough approximation of the real cooling curve by calculating from the heating curve would be difficult, if not impossible. While the differences between the heating and the cooling curves may be negligible from a practical standpoint in some cases, in others they are of very considerable importance. An actual experimental cooling curve would seem to the writers to be the safest way to determine temperature changes during cooling.

In a more detailed and comprehensive manner Bigelow and his collaborators (3) have studied the time-temperature relations of foods during canning. These workers, by the use of a specially constructed thermoelectric apparatus, have carried on extensive investigations upon a wide variety of canned-food materials and have made important contributions to the knowledge upon this subject. In addition to the consideration of both theoretical and practical matters

involved in work of this sort, use has been made of numerous experimental curves, tables, and formulas, which make the work of much value.

Especially useful are the formulas given for calculating from a previously determined curve the time-temperature curves for cans of food having any initial temperature; for calculating curves for cans processed at any temperature from a curve for a can with a known processing temperature; and for calculating curves for a container of any size from an experimental curve determined for a can of known size.

Few cooling curves are given. The statement is made, however, that the temperature will descend during the cooling operation by exactly the same curve that is followed during the processing. What has been said upon this matter in connection with the review of Thompson's article above applies equally here.

Since certain matters discussed in these papers bear directly upon the work herein reported, more detailed reference will be made to them from time to time in the body of this bulletin.

The necessity of properly exhausting cans of food material either by short heating, by filling in the material while hot, or by mechanically removing the air in the can before the final sealing, has long been recognized. It was early believed that the partial vacuum thus formed was largely responsible for the keeping of the food. Later when it was found that food spoilage was due to the activities of microorganisms this idea was abandoned, though the practice of exhausting was continued for other reasons. More recently the work of Weinzirl (10) has focused attention upon the question whether after all the vacuum may not be largely responsible for the keeping of many of our canned foods.

The relation of exhaust and vacuum to swells and springers in canned foods was clearly set forth by Bigelow (1) in 1914. The following year Bitting (4) called attention to the effect which the vacuum has upon the amount of dissolved tin in canned foods and pointed out how the action of the food material on the metal of the container may affect the vacuum.

In 1916 the same author (5) entered into a more detailed consideration of the subject of exhaust and vacuum. Some of the reasons given for exhausting were as follows:

(1) To draw in the ends of the cans, thus giving an index to the condition of the contents.

(2) To minimize the action of the contents upon the container.

(3) To prevent overfilling.

(4) To prevent unnecessary strains on cans.

(5) To produce a desirable effect upon the product itself.

Figures were given for the vacuum produced by heat exhaustion in No. $2\frac{1}{2}$ cans sealed at different temperatures. Tables were given showing the effect of the fill of the can on vacuum, as well as tables showing the amount of vacuum with different sealing temperatures. The relative merits of heat exhaust and mechanical exhaust were discussed, the relation of exhaust and head space to erosions and perforations was emphasized, and other factors influencing vacuum were enumerated.

In 1917 Bitting and Bitting (7) reported upon further studies along this line. Attention was called to the pressure developed in tin cans during processing, which showed very considerable divergence from the pressure calculated from physical laws. These investigators stated also that gases incorporated in the tissues of fruits and in cold-storage products cause a decided increase above normal pressure in processing.

Tables showing the absolute pressure of saturated steam at various temperatures and also tables showing the expansion of water were given by Bitting and Bitting. They discussed also the pressures developed when cans were filled with different quantities of hot and of cold water.

The possible relation of exhaust and vacuum to the black discoloration of corn was pointed out more recently by Bigelow (2).

The material presented in these papers is rich in suggestion and of much practical importance. Through them the practice of exhausting is placed upon a sound scientific basis.

In the present work the writers have found it necessary for their purposes to cover in an experimental way some of the same ground included in the above-mentioned investigations. At the points of contact between the work of the earlier investigators and that herein reported more detailed references will be made.

NEED FOR STUDY OF INITIAL TEMPERATURE IN ITS RELATION TO PRESSURE AND VACUUM.

The problem always before the canner is how to get the best quality in the finished product. In striving for the best quality many things are to be considered, such as selection of the best varieties, prompt transfer from the field to the place of canning, and proper treatment previous to filling the can. But the thing of greatest importance is to secure the proper condition in the can so as to protect the food against microorganisms and at the same time develop and preserve the desirable flavors in the product. A thorough knowledge of conditions in the can, therefore, will facilitate the choosing of the best procedure.

The chief altering factor in the can is the temperature. Proper temperature maintained for a length of time sufficient to prevent

the subsequent development of the organisms causing spoilage must be provided for first, but for the sake of the quality it should not be prolonged beyond the time essential to insure the keeping of the product and the safety of the food for human consumption; in other words, the temperature factor must be under careful control.

Another factor greatly affecting the quality of the finished product is the amount of air present in the can. The presence of air may result in enormous strains on cans, causing leakage and loss, in the discoloration of the product, and in increased activity of the food material upon the metal of the container. In other ways also it has a direct bearing upon the quality of the product. It is evident, therefore, that this factor likewise must be kept under control. This may be accomplished by some method of exhaust.

Inasmuch as under present conditions the exhaust is effected primarily by the use of heat and inasmuch as the initial temperature of the material in the can affects the time-temperature curves, it is apparent that in determining the proper temperature and duration of the processing period the exhaust must be carefully considered. In other words, the exhausting procedure must be standardized before the processing temperatures can be prescribed and the processing periods determined.

As is well known, exhausting may be accomplished in three ways: First, by filling the cans with the material, after it has been heated to the desired temperature, as with corn, sweet potatoes, etc.; second, by subjecting the cans of material to a preliminary heating before sealing; and, third, by mechanically removing the air, or sealing in a vacuum chamber.

Whichever method is used, it is especially important that so far as possible uniform temperatures shall exist throughout the entire mass in the can and that processing shall begin at the earliest possible moment, preferably at once. As has been shown graphically by Bigelow and his collaborators (3, p. 63), unless this is the case the time-temperature curve at the center of the can may actually fall during the first part of the processing period and thus make impossible an accurate knowledge of the temperature changes taking place during the processing period. Under such conditions careful standardization is out of the question.

With these things in mind and with a view to gaining a definite knowledge of the temperature changes taking place under carefully controlled conditions as regards the time-temperature relation in food materials sealed at different temperatures and the relation of these matters to pressures developed and vacuum obtained, the present work was undertaken.

METHODS AND APPARATUS.

DETERMINATION OF PRESSURE.

In the pressure and vacuum studies, preliminary experiments soon showed that the pressure and vacuum gauges commonly used were too coarse and inaccurate for careful work. Because of their mechanical construction they are always open to the danger of becoming weakened, which makes frequent standardization necessary. They also seem abnormally sensitive to barometric pressure, for which corrections are difficult. Their use in this work was therefore abandoned except in certain rough tests mentioned below, and in their place a special mercury manometer was substituted. Figure 1 illustrates the manometer.

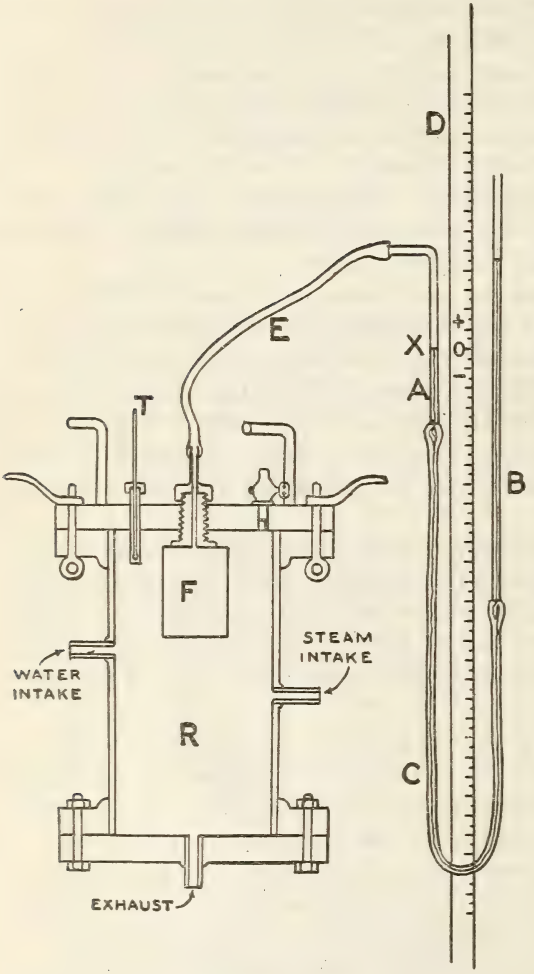

FIG. 1.—The manometer used in the pressure-vacuum tests. *A*, Fixed glass arm of the manometer; *B*, movable glass arm; *C*, flexible rubber tube wound with copper wire connecting glass arms *A* and *B*; *D*, scale, graduated in centimeters or inches; *E*, flexible rubber tube wound with copper wire connecting manometer with the can-sealing device; *F*, test can; *R*, steam retort; *T*, thermometer; 0, zero mark on the graduated scale; *X*, mark on glass arm *A* corresponding with the zero mark on the scale *D*, at which the mercury column in *A* is held constant. The plus and minus signs on the scale indicate the portions of the scale above and below the zero mark, respectively.

This manometer consists of two glass arms, *A* and *B*, which are connected by a flexible tube (*C*) of rubber pressure tubing reinforced with closely wound copper wire to minimize expansion. A scale *D*, so graduated as to allow readings in both directions from 0, is so placed that the zero mark stands at *x* of the glass arm *A*, which represents the constant level of the mercury in that arm. The flexible tube *E*, which is identical in structure with *C*, connects with an air-tight junction

glass arm A with the test can F, located in the retort R, as described for temperature tests in United States Department of Agriculture Bulletin No. 956, entitled "A Study of the Factors Affecting Temperature Changes in the Container during the Canning of Fruit and Vegetables." Retort temperature is controlled by the thermometer T. During the test the pressure which causes the level of the mercury to fall in arm A is compensated for by raising arm B, and the mercury in arm A is therefore maintained at the constant level x, corresponding to the zero graduation on scale D. The volume of gas in the retort side of the apparatus is kept constant and the pressure in centimeters or inches, as desired, read directly from the + portion of the scale. Similarly, the vacuum is read by lowering arm B, to compensate for the rise of mercury in A, and the vacuum is read directly from the — portion of the scale. The can being attached to the cover of the small retort, the flexible tube E allows the prompt removal of the test can from the retort in a few seconds and the cooling of the can either in air or in water, as desired.

This apparatus is very sensitive to slight changes in pressure, demonstrates very quickly any leaks present, and has proved very satisfactory. By means of this apparatus the writers have been able to conduct tests upon all classes of substances in various quantities with different sizes of cans at any initial temperature and retort temperature desired.

DETERMINATION OF TEMPERATURE.

Data upon temperature changes were obtained in the same manner as described in United States Department of Agriculture Bulletin No. 956, and all temperatures, both of retort and can, were made with special carefully standardized mercury thermometers.

In the paper previously reviewed, Bigelow and his collaborators object to the use of a mercury thermometer for this purpose, on the ground that heat is conducted down the stem to the mercury bulb. According to Smithsonian conductivity tables, the conductivity of glass and water is practically the same. It is evident, therefore, that the conductivity of glass is about the same or slightly less than the minimum for any food substance. Since, also, the distance from the ends of the can to the center is greater than the radius, the heat should reach the mercury bulb through the food from the side before it could be conducted down the stem of the thermometer. In the thermocouple used by Bigelow and his collaborators, which is inserted into the can in the same way as the thermometer, the thermal junction is soldered to the end of a bare copper tube, which in turn is soldered to the end of a brass tube, the external portion of which during processing is subjected to the full temperature of the retort, which allows of rapid conduction of heat into the can. With the

conductivity of copper at about 1.0, of brass at about 0.25, and of glass at 0.002, the chances of error from heat conduction are hundreds of times greater with this thermocouple than with the thermometer.

It must be borne in mind that in experimental work with canned foods small inaccuracies are of minor importance. Because of the differences in the consistency of the material, of difficulty in preparing uniform packs, of difficulty in adjusting closely the retort temperatures throughout the entire process, and of other factors, it is practically impossible to check time-temperature curves closer than 0.5° C., and it is doubtful whether a difference of 0.5° C., or perhaps even more with materials of this kind, is of any practical significance.

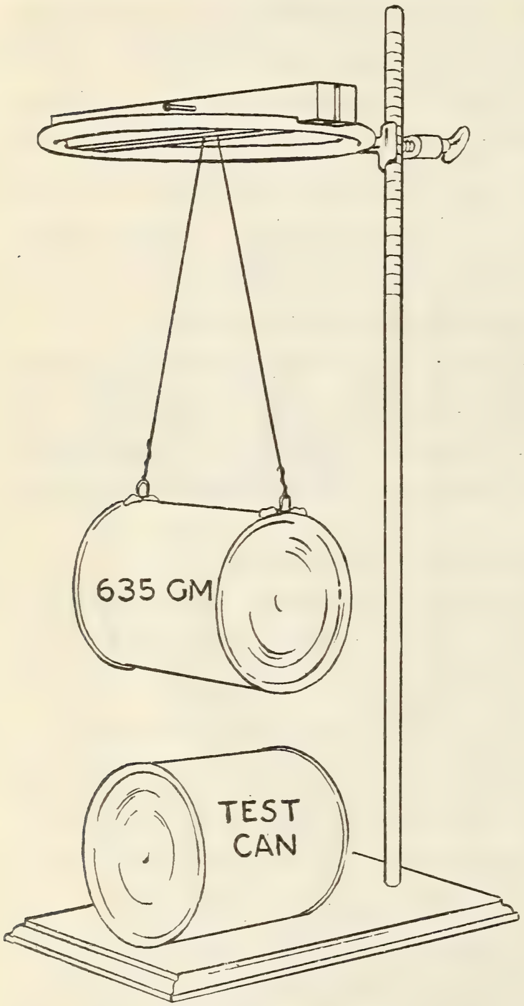

FIG. 2.—Apparatus used in the concussion tests.

PRACTICAL VACUUM TESTS.

In an attempt to determine the optimum temperature for sealing, cans of various materials were prepared in lots which were sealed at the temperatures of 20°, 50°, 60°, 70°, 80°, 90°, and 100° C., respectively. In some cases, instead of this procedure, the cans were exhausted for two, four, or six minutes and then sealed. In each case the lots were divided and one half were tested for vacuum with a common Young's vacuum gauge, and the remainder were subjected to concussion tests to learn to what extent the vacuum affects the denting and collapsing of cans in ordinary handling.

CONCUSSION TESTS.

The apparatus illustrated in figure 2 was employed in the concussion tests.

This apparatus consists merely of an ordinary laboratory ring-stand support, the standard of which is graduated in centimeters. The adjustable ring supports a wooden block, which is sawed lengthwise to allow the entrance of a fine copper wire attached to a weighted can. A metal pin in this block holds the wire until ready for release. The test can is placed on the platform at right angles, with the weighted can suspended above in such a way that the weight in falling strikes it midway between the ends. The weight is raised to the desired height by adjusting the ring. The weight is prepared by cutting a hole in the side of an ordinary No. 2 can with both ends crimped on and running into it the required quantity of molten lead while the can is lying on its side. This, in addition to furnishing the required weight, lends rigidity to the can and prevents its denting. In these tests the over-all weight of the can was 635 grams, which corresponds closely to the weight of an ordinary No. 2 can of food.

With this arrangement the can of food to be tested may be subjected to the most rigid treatment and will thus give an index to its relative resistance to handling when subjected to variable exhausts.

CONTAINERS.

The containers used in these tests were the standard packers' cans. Because of their adaptability for ready attachment to the other apparatus the hole-and-cap type, with ends mechanically crimped on, was employed for the most part, though the cans used for the concussion and rough vacuum tests described later were of the open-top type. The great difficulty in finding cans with air-tight seams made it necessary in all cases where great accuracy was required to solder all ends over the seam before making a test. In the canning tests covered by this and other studies during the last season, as high as 18 to 20 per cent of the cans have been found to show visible leaks at the factory ends when they were taken from the retort. It is to be expected that small leaks will show up when great pressures are developed, but certainly visible leaks should not appear to this extent where common canning practices are employed, as was true in these cases.

THEORETICAL PRESSURES AND VACUUMS.

The development of pressure and the formation of vacuum follow the well-known physical laws for gases and saturated vapors with changes of temperature. A consideration of the theoretical

values as affecting canning operations is therefore important for the present work; and while it is not possible to calculate by formulas the actual results which will be obtained in practice, because of other variable factors, the theoretical pressures and vacuums falling within the range of the present experiments serve as a background for the work and as a guide in the interpretation of the experimental results.

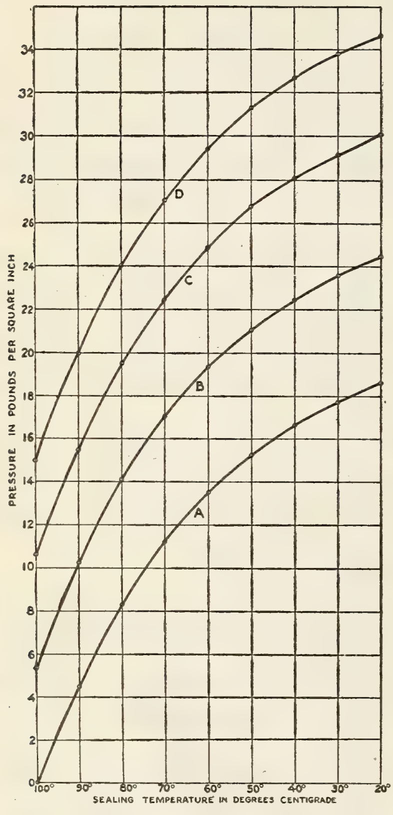

FIG. 3.—Theoretical maximum-pressure curves for a nonexpansible can containing air and sufficient water to give saturation, when sealed at different uniform temperatures and processed in the retort at 100°, 109°, 116°, and 121° C. Calculations are made on the basis of mean barometric pressure. Curve for can processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C.

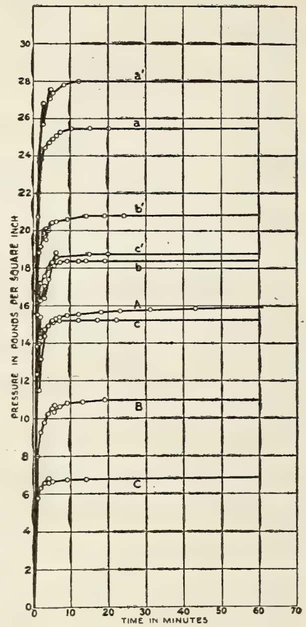

FIG. 4.—Experimental time-pressure curves for No. 2 cans containing 550 c. c. of distilled water sealed at uniform temperatures and processed for 1 hour. Curve for can sealed: *A*, At 20° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a′*, at 20° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b′*, at 70° C. and processed at 121° C.; C, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c′*, at 80° C. and processed at 121° C.

Theoretical pressure curves.—In figure 3 are shown the theoretical maximum-pressure curves for a nonexpansible can containing air and a sufficient quantity of water to give saturation, when

sealed at various temperatures and processed at 100°, 109°, 116°, and 121° C. These are calculated for the mean barometric pressure.

These curves show how relatively great pressures are developed when containers are sealed at the low temperatures and bring out clearly the fact that when the sealing temperature is increased the pressures are not reduced in the same proportion, but fall off with increasing rapidity as the sealing temperature of 100° C. is approached. They also serve as a general guide in the selection of the most desirable sealing temperatures.

Relation of time to pressure changes.—The relation of time to the pressure changes during processing is illustrated in figure 4, which shows the time-pressure curves obtained for the No. 2 can containing 550 c. c. of water.

Attention is directed especially to the steepness of the curves during the first minute of the processing and to the fact that the pressure shortly reaches an equilibrium. The close correlation of the pressure changes and time-temperature changes in the can is clearly shown. The comparison of the form of these curves with the curves for the various food materials shown later will be found of much interest. Sharp breaks in the curves, as in the others which follow, show where the sudden bulging of the cans occurred.

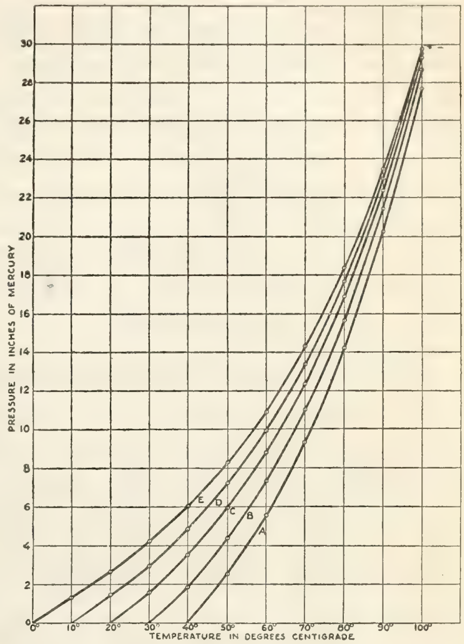

FIG. 5.—Theoretical vacuum curves for a noncontractile can containing air and sufficient water to give saturation when sealed at different uniform temperatures and read at 0°, 10°, 20°, 30°, and 40° C. Calculations are based upon mean barometric pressure. Curve for readings made: *A*, At 40° C.; *B*, at 30° C.; *C*, at 20° C.; *D*, at 10° C.; *E*, at 0° C.

Theoretical vacuum curves.—Of equal, if not of greater importance, is the matter of vacuum obtained as the result of various canning operations. Here, again, theoretical figures serve as a background for experimental work and furnish information of much practical value. Figure 5 shows the theoretical vacuum curves for a noncontractile receptacle containing air and saturated vapor when sealed at various temperatures and cooled to the uniform temperature of 0°, 10°, 20°, 30°, and 40° C. These are calculated on the basis of mean barometric pressure.

These curves show how, as the sealing temperature is increased, the pressure is developed and bring out the fact that as the cooling temperature approaches 100° C. the vacuum increases progressively. They also show how the vacuum is affected by the temperature to which it is cooled. For example, a can sealed at 70° C. and subsequently cooled to 20° C. should give a theoretical vacuum of about 12.3 inches; if cooled to 30° C., a vacuum of about 10.9 inches; or if cooled to 0° C., a vacuum of 14.3 inches. They likewise illustrate how cans of food having a low vacuum, although sound and healthful, may, when stored in warm places or shipped to hot climates, show no vacuum at all, or possibly in some cases even develop springers. For instance, a can of food which at 10° C. showed approximately 3 inches of vacuum when held at 30° C. would have no vacuum at all. Similarly, though of less importance, it shows how cans having relatively high vacuums would suffer more in shipment and handling in low temperatures, due to the denting or collapsing of the cans. One may, therefore, gain from these curves an idea of the approximate vacuums to be expected under conditions within the range of canning operations.

EXPERIMENTS WITH DISTILLED WATER FOR COMPARISON.

As is well known in canning, theoretical values are practically never obtained because numerous variable factors enter in which influence practical results. In order to discover what and how great these variable factors are, to learn how closely the theoretical and the practical results agree, and to obtain information which would serve as a base line for the comparison of various food materials when canned in different ways, preliminary pressure and vacuum experiments were made with water, using No. 2 and No. 3 tin cans. The experiments were conducted as follows: The test cans were prepared by carefully soldering all seams and joints to insure against leakage; the required quantity of water was measured in; the can was placed in the retort in the manner illustrated and held under carefully controlled conditions until both can and contents came to the desired uniform temperature throughout; the can was then sealed. The barometric reading at the time of sealing was noted and the pressure determinations immediately performed. In this way tests were made using various quantities of water, sealed at different temperatures, and processed in the retort at 100°, 109°, 116°, and 121° C.

PRESSURE STUDIES.

Pressure readings obtained in tests.—Table 1 gives the results of maximum-pressure tests upon No. 3 cans with 100 c. c. and with 950 c. c. of water.

TABLE 1.—*Maximum-pressure tests with No. 3 tin cans containing 100 c. c. and 950 c. c. of distilled water.*

Temperatures (° C.).		100 c. c. water.		950 c. c. water.		Temperatures (° C.).		100 c. c. water.		950 c. c. water.	
Sealing.	Processing.	Barometer.	Pressure per square inch.	Barometer.	Pressure per square inch.	Sealing.	Processing.	Barometer.	Pressure per square inch.	Barometer.	Pressure per square inch.
			Lbs.		*Lbs.*				*Lbs.*		*Lbs.*
20	100	29.92	17.06	30.18	14.60	70	100	30.05	10.67	30.18	9.88
	109	29.92	22.70	30.18	20.25		109	30.05	16.26	30.18	15.49
	116	29.92	28.23	30.18	25.40		116	30.05	21.78	30.18	20.74
	121	29.92	32.89	30.18	29.52		121	30.05	26.26	30.18	24.91
50	100	30.08	13.87	30.15	10.99	80	100	29.95	7.97	30.16	7.30
	109	30.08	19.51	30.15	16.36		109	29.95	13.37	30.16	12.70
	116	30.08	25.10	30.15	21.44		116	29.95	18.95	30.16	17.64
	121	30.08	29.60	30.15	25.02		121	29.95	23.50	30.16	21.66
60	100	30.11	12.45	....	....	90	100	29.92	4.66	30.05	4.41
	109	30.11	18.04	....	....		109	29.92	10.12	30.05	9.51
	116	30.11	23.50	....	....		116	29.92	15.46	30.05	14.36
	121	30.11	28.10	....	....		121	29.92	20.06	30.05	17.79

Too much importance, of course, should not be attached to one set of figures, as results with individual cans vary somewhat, but the outstanding features shown here have been confirmed by repeated experiments, and the figures presented closely approach the average.

Leading facts disclosed.—From all these tests the following facts seem clear:

(1) With water the pressures developed are always below the theoretical (that with some food materials this does not hold in all cases will be shown later).

(2) The higher the retort temperature, the greater the variation from the theoretical pressures.

(3) The higher the initial temperature, the nearer to the theoretical does the pressure come.

(4) The larger cans show a somewhat greater divergence from the theoretical values than the smaller.

(5) With water, the smaller the head space the less the experimental pressures obtained. The fact that with water the smaller the head space the less the experimental pressures obtained is likewise borne out by experiments with No. 2 cans, using 50 and 550 c. c. of water, the tabulation of the results of which is omitted for lack of space.

Influence of head space.—With cans entirely filled and sealed at any temperature below 100° C. the experimental pressures have been found less than where a head space was allowed. This is explained, of course, by the fact that under these conditions the prime factors operating are vapor pressure and expansion of the water, whereas when a head space is allowed the air pressure also contributes to the

final result. This finding is entirely at variance with the statement of Bitting and Bitting (7, p. 27) that when the container is entirely filled the pressure is greatly increased.

The explanation of the decrease of maximum pressure with decrease of head space is found by a glance at the tables on the distortion of cans and the expansion of water and the theoretical curves of figure 3. By comparison of the expansion of water with the cubical expansion of the can (Tables 1 and 2) it will be seen that the distortion of the can under pressure is always greater than the expansion of water, which results in the creation of a greater head space. Consequently, the ratio between the head space and the distortion of the can is greater the smaller the head space, and therefore with decrease in head space a slight decrease in maximum pressure is to be expected. The greater distortion of the larger can accounts for the greater variation from the theoretical.

Distortion of can and increase in volume.—Every change in pressure causes more or less distortion of the can, which alters its cubical contents. How great this distortion actually is is shown by Table 2, which gives the experimental findings on the increase in volume in No. 2 and No. 3 tin cans when subjected to various internal pressures. These figures present the averages of a number of tests.

TABLE 2.—*Increase in volume of No. 2 and No. 3 tin cans as the result of distortion caused by internal pressures.*

Pressure per square inch in can.	Increase in volume (c. c.).		Pressure per square inch in can.	Increase in volume (c. c.).	
	No. 2 cans.	No. 3 cans.		No. 2 cans.	No. 3 cans.
2½ pounds	5.4	28.3	20 pounds	26.5	65.6
5 pounds	12.1	37.1	25 pounds	31.2	76.9
10 pounds	18.0	46.0	30 pounds	36.7	....
15 pounds	22.6	54.6			

It will be seen that within the range of canning operations the cubical content of cans may be increased up to 5 per cent or more, depending somewhat upon the size and strength of the individual cans used.

The increase in volume due to distortion of the can explains the decrease in pressure, and since this distortion increases with the higher temperatures greater variations from the theoretical must take place. Inasmuch as sealing at the higher temperatures causes less strain on the can and consequently less distortion when subsequently processed, the theoretical values are more closely approached.

Of less importance also is the influence of the linear expansion of the metal of the can, due to the rise in temperature.

Another fact of much importance in connection with all pressure and vacuum tests is that individual cans vary considerably in their resistance to pressure, whether internal or external. This fact accounts in part for some of the irregularities in the experimental data presented.

Expansion of water.—The expansion of the water due to the rise in temperature likewise has some effect upon the pressure developed. This, while unimportant where the quantity of water is small, may have a considerable influence where the head space is reduced to a minimum, as decreasing the volume of gas in the head space by one-half through expansion of the water after sealing theoretically doubles the pressure developed by the expansion of the inclosed air.

In Table 1 no corrections have been made for this expansion. The tendency, however, is always to increase the variations between the experimental and the theoretical figures.

Table 3, which has been taken from the work of standard authorities (see Smithsonian Physical Tables, Fowle, 7th revised edition, 1920, p. 120; also Kent's Mech. Eng. Pocketbook, 9th edition, 1916, p. 716), shows the increase in volume of a unit quantity of water when passing through the range of temperature with which the present work is concerned.

TABLE 3.—*Volume of water at different temperatures.*

[The mass of 1 cubic centimeter at 4° C. is taken as unity.]

Temperature (° C.).	Volume.	Temperature (° C.).	Volume.	Temperature (° C.).	Volume.
0	1.00013	40	1.00782	85	1.03237
4	1.00000	45	1.00985	90	1.03590
5	1.00001	50	1.01207	95	1.03955
10	1.00027	55	1.01448	100	1.04343
15	1.00087	60	1.01705	110	1.0515
20	1.00177	65	1.01979	115.5	1.0560
25	1.00293	70	1.02270	121.1	1.0661
30	1.00434	75	1.02576		
35	1.00598	80	1.02899		

Table 4, which is based upon the foregoing, shows the actual increase in volume of water in No. 2 and No. 3 tin cans when sealed at various temperatures and processed at 100°, 110° 115.5°, and 121.1° C., the initial volume of the water in the No. 2 can being taken as 550 c. c. and in the No. 3 as 950 c. c. The figures are self-explanatory.

TABLE 4.—*Increase in the volume of water in No. 2 and No. 3 tin cans when processed at different temperatures, the initial volume in No. 2 cans being 550 c. c. and in No. 3 cans, 950 c. c.*

[Based on Smithsonian tables.]

Temperatures (° C.).		Volume (c. c.).			
		No. 2 cans.		No. 3 cans.	
Sealing.	Processing.	Total.	Increase.	Total.	Increase.
20	100	572.8	22.8	989.4	39.4
	110	577.2	27.2	997.0	47.0
	115.5	579.7	29.7	1,001.3	51.3
	121.1	585.3	35.3	1,010.9	60.9
70	100	561.1	11.1	969.2	19.2
	110	565.4	15.4	976.7	26.7
	115.5	567.9	17.4	984.9	34.9
	121.1	673.3	23.3	990.3	40.3
80	100	557.7	7.7	963.3	13.3
	110	562.0	12.0	970.8	20.8
	115.5	564.4	14.4	974.9	24.9
	121.1	569.8	19.8	984.2	34.2

Relation of barometric pressure.—A factor of considerable importance concerned with vacuum in cans is the barometric pressure, especially as related to differences in altitude. Table 5 shows the differences in barometric pressure for altitudes ranging from sea level to approximately 6,000 feet and how, for example, food materials packed at or near sea level would lose in vacuum by over 3 inches, under identical temperature conditions, when shipped to a place 3,000 feet above sea level. This loss would be increased, of course, if those shipments were made to hot climates or during the summer.

TABLE 5.—*Barometric pressure for different altitudes.*

[Taken from Smithsonian Meteorological Tables, 4th rev. ed., 1918, pp. 136–137.]

Altitude.	Barometric pressure.	Altitude.	Barometric pressure.	Altitude.	Barometric pressure.	Altitude.	Barometric pressure.
0 (sea level)	29.90	607 feet	29.24	1,504 feet	28.29	3,998 feet	25.81
100 feet	29.79	700 feet	29.14	1,999 feet	27.78	4,498 feet	25.34
210 feet	29.68	803 feet	29.03	2,502 feet	27.27	5,006 feet	24.80
302 feet	29.57	906 feet	28.92	3,005 feet	26.77	5,503 feet	24.42
403 feet	29.46	1,000 feet	28.82	3,497 feet	26.29	5,997 feet	23.98
505 feet	29.35						

While these matters may not be of great importance it is probable that the unfortunate experience of some canners has been due to some of these factors or to a combination of them.

VACUUM STUDIES.

Vacuum readings obtained in tests.—To determine how closely experimental results with tin cans would agree with the theoretical

figures, to assist in the selection of the best sealing temperatures, and to obtain a base line for comparing various food materials, vacuum tests were made with No. 2 and No. 3 cans containing 550 and 950 c. c. of water, respectively, sealed at different temperatures and cooled to room temperature. The experimental data are shown for the No. 3 cans in Table 6. Figures for the No. 2 cans are omitted, as they do not vary essentially from those of the No. 3 cans except in having a slightly greater vacuum, due to greater resistance to external pressure.

TABLE 6.—*Vacuum readings obtained with No. 3 tin cans containing 950 c. c. of water sealed at different temperatures and cooled.*

Temperatures (° C.).		Barometer readings.		Vacuum reading (inches of mercury).
At sealing.	After cooling.	At sealing.	After cooling.	
50	16¼	30.19	30.43	8.62
60	18	30.39	30.18	10.12
70	19	30.18	30.16	11.75
80	20	30.16	30.05	13.87
90	19¼	30.05	30.18	19.00

Leading facts developed in comparisons of these findings with the theoretical curves show the following:

(1) At the sealing temperatures of 70° C. and above the vacuums obtained are below the theoretical. This is to be expected, of course, inasmuch as the same factors which affect recorded pressures, discussed above, are operative here, although working in the other direction. That is, contraction takes place instead of expansion; the temperatures are lowered instead of increased; the can is distorted inward by external pressure instead of outward, etc.

(2) The higher the sealing temperature the greater the variation from the theoretical vacuums.

(3) In these tests the cans sealed at the lower temperatures show vacuums slightly above their theoretical values. This was found, after examining the cans, to be due to permanent distortion of the cans during processing, for the vacuum readings were made on the cans employed in the above pressure tests which after cooling did not return to their normal shape. If the cans are sealed at these temperatures and cooled immediately to the desired temperature, the vacuum is slightly below the theoretical.

RATE OF TEMPERATURE CHANGE WITHIN THE CAN.

From the above statement it is obvious that in order to avoid undue strain upon cans, and for other reasons mentioned, the temperature of sealing should be considerably above room temperature. The question then immediately arises, How will this affect the length of time required to secure the proper temperature in the can? To shed light upon this matter and to obtain a base line for the comparison of the various food substances, tests were made upon the rate of temperature changes in distilled water. Figure 6 shows the results of these

tests, using No. 3 cans sealed at different temperatures and processed at 116° C.

The temperature of the retort is reached only one to one and one-half minutes sooner when the initial temperature is 80° than when it is 20° C. A comparison of these curves with similar ones for different food substances shown later will be found to be of interest. Cooling curves are also shown for the No. 3 can cooled from 116° in water at constant temperature to 60° and 20° C., respectively. While, as in the heating, the temperature changes within the can take place very rapidly, the heating and the cooling curves are not the exact reverse

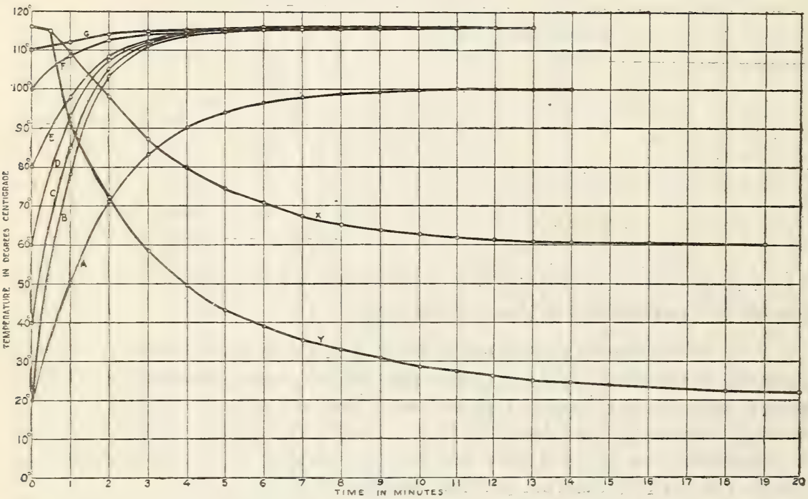

FIG. 6.—Experimental time-temperature curves for distilled water in No. 3 tin cans, starting at different uniform temperatures and processed at 116° C. The heating curve is shown for a can starting at 20° C. and processed at 100° C.; and curves showing the rate of cooling in water at different temperatures. Curve for can starting: *A*, At 20° C. and processed at 100° C.; *B*, at 20° C. and processed at 116° C.; *C*, at 40° C. and processed at 116° C.; *D*, at 60° C. and processed at 116° C.; *E*, at 80° C. and processed at 116° C.; *F*, at 100° C. and processed at 116° C.; *G*, at 110° C. and processed at 116° C.; *X*, at 116° C. and cooled in water at 60° C.; *Y*, at 116° C. and cooled in water at 20° C.

of each other. This is due in part, of course, to the fact that the viscosity of water changes with changes in temperature. As the temperature in the can approaches the temperature of the cooling bath there is a flattening out of the curve, due in part to the increase in viscosity of the water, which is much more marked than in the corresponding portion of the heating curve, where the viscosity is continuously diminishing and the time required to effect the complete change is materially lengthened.

Figure 7 shows the rate of temperature change at the center of a quart glass jar with water sealed at different temperatures and processed at 100° C.

The effect of initial temperature is easily seen from the curves. The temperature of the retort is reached six or seven minutes sooner when the initial temperature is 80° C. than when it is 20° C. It is apparent, therefore, that the initial temperature is of more significance when canning in glass than when canning in tin in those substances where there is free liquid filling the interspaces of the product.

Another matter of much importance is the study of the changes in temperature necessary to secure the proper exhaust. When a No. 2 can of water having an initial temperature of 20° C. is exhausted for 1 minute at 100° C. the temperature reaches to about 60° C. A No. 3 can reaches about 50° C. The rate of change of temperature

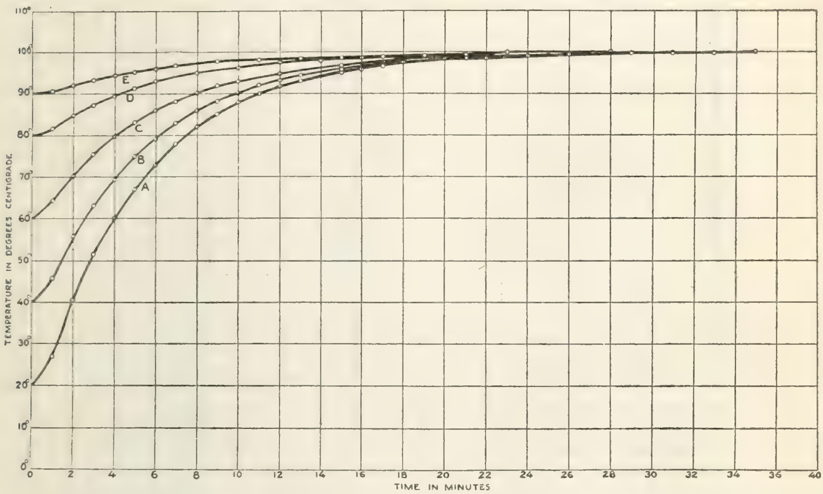

Fig. 7.—Experimental time-temperature curves for quart glass jars of distilled water, starting at different temperatures and processed at 100° C. Curve for jar starting: *A,* At 20° C.; *B,* at 40° C.; *C,* at 60° C.; *D,* at 80° C.; *E,* at 90° C.

when exhausted at 100° is shown in figure 6, curve A. The application of these facts to the exhausting of various food substances will be considered and illustrated later.

EXPERIMENTS WITH SPECIFIC FOOD MATERIALS.

STRING BEANS.

PRESSURE STUDIES.

The tests upon string beans were carried out as follows: The beans were gathered fresh from the field, washed, broken into pieces 1 to 1½ inches in length, and then blanched in boiling water for four minutes. For each one of the tests with the No. 2 can 350 grams of beans were used and 220 c. c. of liquor, which gave approximately normal head space. In the case of the No. 3 can, 600 grams of beans and 360 c. c. of liquor were used.

Figure 8 shows the pressure curves for the No. 2 can when sealed at the temperatures of 22° to 24½°, 70°, and 80° C. and processed at 100°, 116°, and 121° C. Figure 9 shows the same for the No. 3 can.

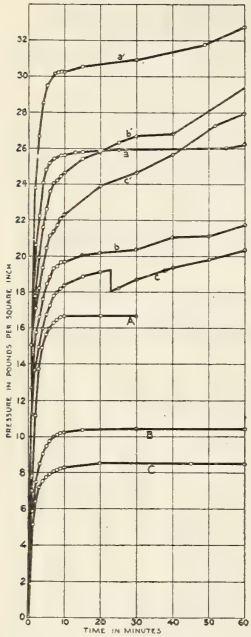

FIG. 8.—Experimental time-pressure curves for No. 2 cans of string beans sealed at different uniform temperatures and processed for 1 hour at 100°, 116°, and 121° C., 350 grams of beans, 220 c. c. of liquor. Curve for can sealed: *A*, At 24½° C. and processed at 100° C.; *a*, at 24½° C. and processed at 116° C.; *a'*, at 22° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

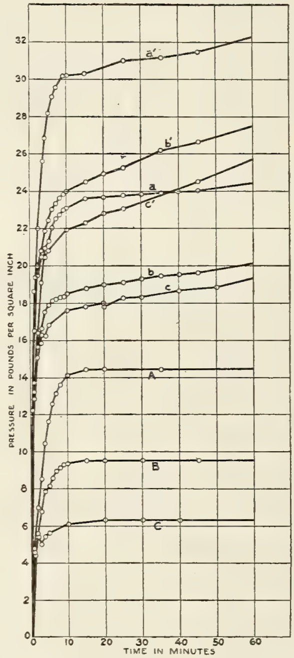

FIG. 9.—Experimental time-pressure curves for No. 3 tin cans of string beans sealed at different uniform temperatures and processed at 100°, 116°, and 121° C., 600 grams of beans, 360 c. c. of liquor. Curve for can sealed: *A*, At 20¾° C. and processed at 100° C.; *a*, at 30° C. and processed at 116° C.; *a'*, at 22° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The form of the curves during the first few minutes of the process is entirely similar to those for distilled water, and in the case of those cans processed at 100° C. the entire curves agree closely. The maximum pressures are approached in 15 minutes. Striking differences

from the distilled-water curves are noted, however, in the case of those curves for cans processed at 116° and 121° C., in which an equilibrium is not attained throughout the entire period of the tests. Furthermore, these differences are increased with the higher processing temperatures, the final portion of the curves for cans processed at 121° C. being steeper than those for cans processed at 116° C. That this has no correlation with the rate of heat penetration is shown by the fact that the increase in pressure is continued long after the equilibrium of temperature has been reached. Experiments show that a temperature equilibrium is reached in string beans in about 15 minutes in the No. 2 and in 18 to 22 minutes in the No. 3 can. In one case during the present tests the pressure continued to increase for four hours after the processing was begun, at which time the experiment was terminated.

This seems to indicate that at the higher temperature there is a decomposition of the material in the can, with a consequent liberation of gases. It was thought that the setting free of hydrogen by the action of the food material on the metal of the container, as pointed out by Bigelow (1) might explain this result, but comparative tests, using both plain and enameled cans under these conditions, failed to give evidence in support of this view.

These curves also illustrate how strains are greatly lessened by sealing at as high temperatures as practicable, especially when processing is to be done at the higher retort temperatures. It will be seen that even when cans are sealed at temperatures as high as 80° C. the pressures obtained are well above the theoretical values.

The processing period in these tests, except in the single instance noted, was 1 hour. This may not conform to regular practice, but the maximum pressures for any period less than this will be shown on these curves, for when the steam in the retort is cut off the pressure in the can begins to fall almost immediately.

The actual strain on the can at any time during the process may be found by subtracting the retort pressure from the pressure indicated for that time in the curve. When the retort pressure is released, however, the strain on the can is greatly increased. If a complete release of pressure in the retort should be effected instantaneously the full pressure indicated would be felt, but the gradual decline in retort pressure in practice favors the can somewhat. The greatest strain occurs when the pressure in the retort reaches zero, but at this point the strain is, however, only 3 to 5 pounds, or (in some cases more than this) less than the maximum pressure indicated in the curve. The extent of this variation from indicated pressures is dependent upon the temperature of sealing, the processing temperature, the nature of the material, the amount of bulging of the can, and the rate of release of pressure in the retort. When processing is done at

100° C. there is no retort pressure to counterbalance that of the can, and consequently the pressures indicated represent actual strains on the cans.

Sharp breaks and occasional irregularities in the form of the curves are due to sudden bulging and gradual distortion of the cans. Small variations due to differences in the resistance of individual cans are to be noted.

VACUUM STUDIES.

Vacuum tests were made upon the cans used in the pressure tests recorded here by cooling the cans to about room temperature and then reading the vacuum with the mercury manometer, as previously described. Table 7 shows the results obtained for the No. 2 cans. Figures for the No. 3 cans are omitted, as, aside from showing a slightly smaller vacuum, due primarily to the lesser resistance of the larger can to external pressure, they are similar.

TABLE 7.—*Vacuum tests with string beans.*

Temperatures (° C.).			Barometer reading.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.	At sealing.	After cooling.	
70	100	$20\frac{1}{2}$	29.89	29.86	$12\frac{1}{8}$
	116	$19\frac{3}{8}$	29.86	29.86	$11\frac{3}{4}$
	121	$18\frac{7}{8}$	29.86	30.05	$11\frac{3}{4}$
80	100	$22\frac{1}{2}$	29.86	29.82	$15\frac{3}{8}$
	116	$18\frac{1}{2}$	30.05	30.05	$13\frac{3}{4}$
	121	19	30.05	30.05	$13\frac{1}{16}$

These figures show that experimental vacuums in string beans are always below the theoretical and that the higher the processing temperature employed the lower the vacuum obtained. This may amount to 2 inches or more. This may be due in part to the pressure of air included in the material which is not expelled during the preliminary blanching and in part to individual differences in cans, but it is probably due primarily to the liberation of gases during the processing.

Cans of string beans in lots sealed at 20°, 50°, 60°, 70°, 80°, 90°, and 100° C. were prepared for vacuum readings and for concussion tests, but the percentage of leaky cans was so great that the results were not considered of sufficient value to present here.

HEAT PENETRATION.

From the foregoing discussion of pressures developed in the can it is obvious that sealing temperatures well above room temperatures should be employed when canning in tin. It is important, therefore, to have a full knowledge as to the temperature changes occurring when the initial temperatures are different. Figure 10 shows the effect of

different initial temperatures on the rate of temperature change in a No. 2 can of string beans packed rather closely and processed at

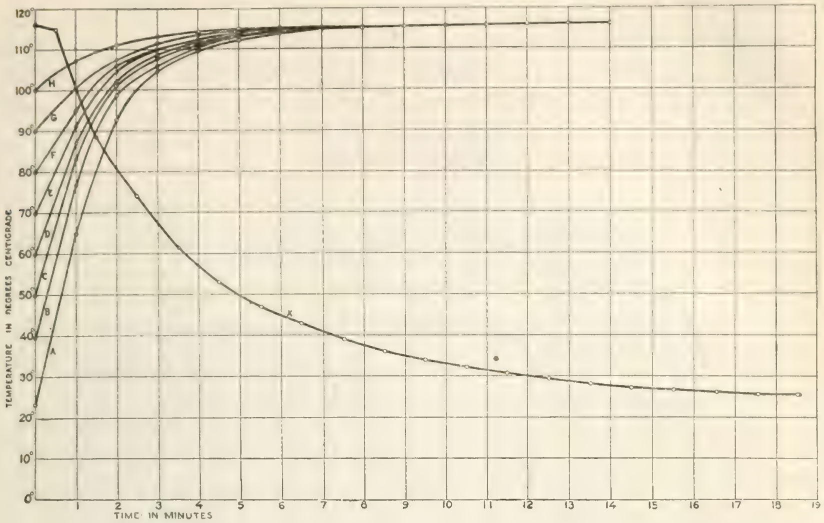

FIG. 10.—Experimental time-temperature curves for No. 2 cans of string beans, starting at different uniform temperatures and processed at 116° C. Curve is also shown for cooling in water at 25° C. Curve for can starting: *A*, At 23° C.; *B*, at 40° C.; *C*, at 50° C.; *D*, at 60° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90° C.; *H*, at 100° C.; *X*, at 116° C. and cooled in water at 25° C.

116° C. The cooling curve for a No. 2 can cooled in water having a constant uniform temperature of 25° C. is also given.

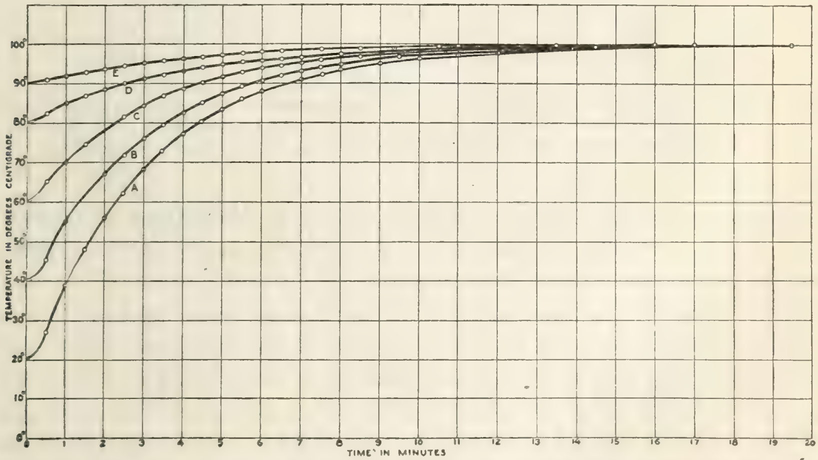

FIG. 11.—Experimental time-temperature curves for string beans in quart glass jars, starting at different uniform temperatures and processed at 100° C. Curve for jar starting: *A*, At 20° C.; *B*, at 40° C.; *C*, at 60° C.; *D*, at 80° C.; *E*, at 90° C.

In figure 11 are shown the experimental heat-penetration curves for beans in a quart glass jar processed at 100° C.

Figure 12 shows curves for a No. 2 can of beans not packed so closely as in the test cans of figure 10, but processed at 100°, 116°, and 121° C.

Figure 13 is the same for a No. 3 can, and in addition the curve for cooling in water at the constant temperature of 20° C. is shown.

A study of the foregoing curves shows that the retort temperature is reached only slightly sooner in the No. 2 can sealed at 80° than in the can sealed at 20° C. and that the effect of differences in initial

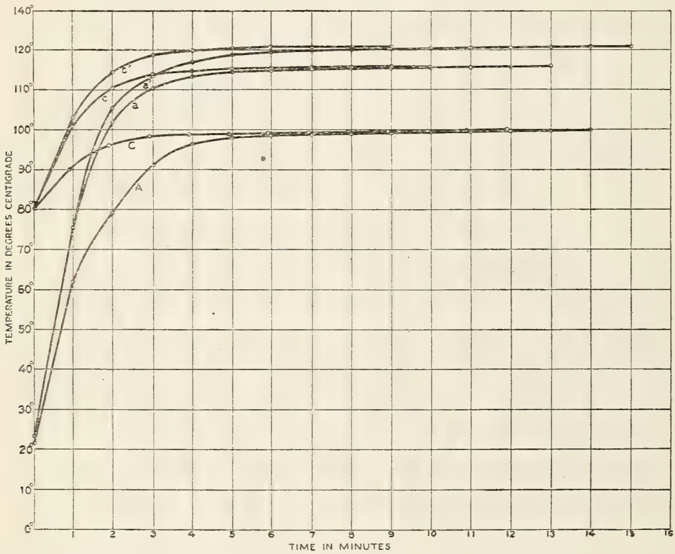

FIG. 12.—Experimental time-temperature curves for No. 2 cans of string beans, starting at different uniform temperatures and processed at different temperatures. Curve for can starting: *A*, At 21° C. and processed at 100° C.; *a*, at 23° C. and processed at 116° C.; *a'*, at 23° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

temperature is more marked when canning in glass than when canning in tin, since the jar starting at 80° requires six or seven minutes less to reach retort temperature than that started at 20° C.

The differences in the heating curves of cans sealed at the various initial temperatures are of relatively small practical importance in substances like string beans and need be considered only when the minimum processing periods are employed. This accounts for the rather uniform results obtained in some canning practices where the initial temperatures vary considerably. It should be remembered, however, that the total amount of exposure to heat is somewhat greater with the higher initial temperature.

As previously noted, the time-temperature curves both for the heating and the cooling are similar to those for distilled water, and

here again is emphasized the fact that the cooling curves are not the exact reverse of the heating curves, for the final portion of the cooling curve is flatter than the corresponding portion of the heating curve. No curves for cooling in air are shown here, but tests show that it is very much slower than cooling in water.

PEAS.

PRESSURE STUDIES.

Peas used for the pressure tests were shelled, blanched in boiling water for four minutes, drained, and then weighed into the test cans.

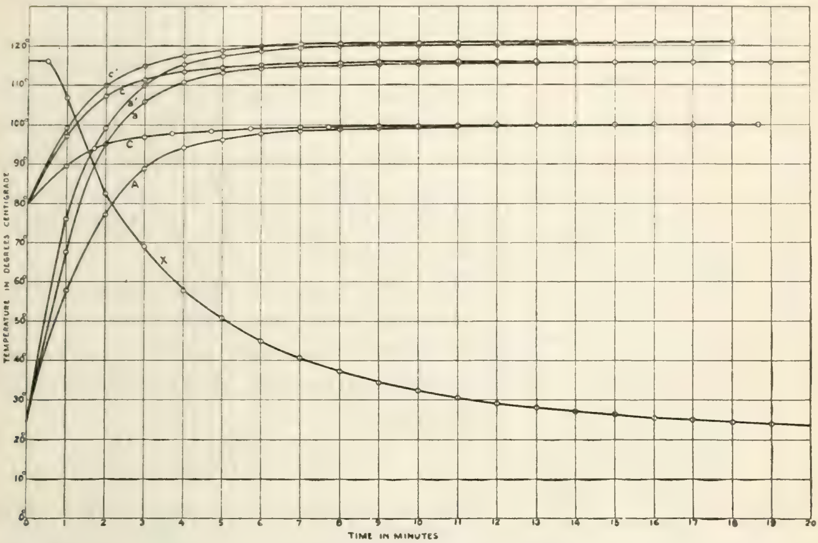

FIG. 13.—Experimental time-temperature curves for string beans in No. 3 tin cans starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curve is also shown for cooling in water at 20° C. Curve for can starting: *A*, At 26° C. and processed at 100° C.; *a*, at 26° C. and processed at 116° C.; *a′*, at 25° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c′*, at 80° C. and processed at 121° C. *X*, Cooling curve for can starting at 116° C. and cooled in water at 20° C.

For the No. 2 can 400 grams of peas and 170 c. c. of liquor were used. The cans were sealed at the initial uniform temperatures of 20°, 70°, and 80° C., respectively, and processed for one hour at 100°, 116°, and 121° C. Figure 14 shows the time-pressure curves for these cans, together with one curve for unblanched peas sealed at 19° and processed at 116° C.

As in the case of string beans, cans processed at 100° C. approached an equilibrium of pressure in a length of time corresponding closely to that required to reach a temperature equilibrium, that is about 15 minutes. At the higher processing temperatures the continued rise in pressure is again noted, though in the case of the cans sealed at

20° and processed at 116° and 121° C., respectively, the pronounced and repeated bulging of the cans masks this effect. The decomposition of the material under test, if such is the explanation, is less marked than in the string beans, but is nevertheless exhibited.

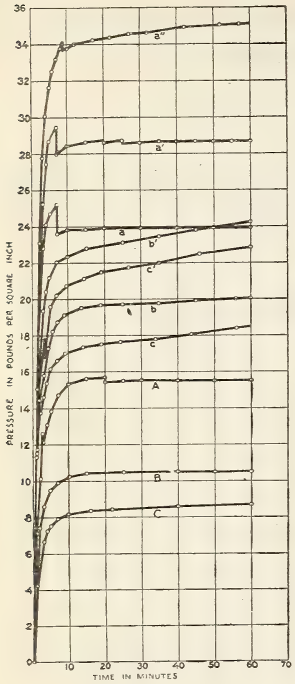

FIG. 14.—Experimental time-pressure curves for peas in No. 2 tin cans sealed at different uniform temperatures and processed at 100°, 116°, and 121° C.; 400 grams of peas, 170 c. c. of liquor. Curve for can sealed: *A*, At 20° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a'*, at 20° C. and processed at 121° C.; *a''*, at 19° C. and processed at 116° C., peas unblanched; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The relation of blanching to the development of pressures is clearly shown by the comparison of the curves for the blanched and the unblanched peas sealed at low temperatures and processed at 116° C. Approximately 11 pounds greater pressure was developed in the can of unblanched material.

In the work with peas it has been observed that the stage of maturity, the amount of blanching, and the fullness of the can have more or less effect upon the pressure developed. The influence of these factors is not here illustrated with curves, however.

The maximum pressures attained during the period of processing used in these tests (60 minutes) were slightly below the theoretical values, but above those for distilled water.

VACUUM STUDIES.

The vacuum readings made on the cans used in the pressure tests gave results entirely comparable with those for string beans. The vacuums obtained were somewhat below the theoretical values and slightly above those for beans. The effect at the higher temperatures was again observed, the reading in the case of the cans processed at 116° and 121° C. being lower by approximately 2 inches than those processed at 100° C.

Those factors which affect the development of pressure in peas likewise influence the vacuum. The amount of blanching, the maturity of the peas, the liberation of gases during processing, the bulging of cans, and the individual variations in the resistance of cans to external pressure all affect the vacuum readings.

In concussion tests upon cans in lots sealed at the various temperatures the results were somewhat variable, but differences in the resistance of No. 2 cans to denting did not seem to be very marked with sealing temperatures up to 70° or 80° C. Above 80° the susceptibility to denting became more and more marked and between 95° and 100° C. the cans usually collapsed spontaneously. The No. 3 cans were more susceptible to denting than the No. 2 size and their susceptibility became more and more marked above 75° C. With sealing temperatures between 90° and 95° C. the can usually collapsed spontaneously or with very slight pressure.

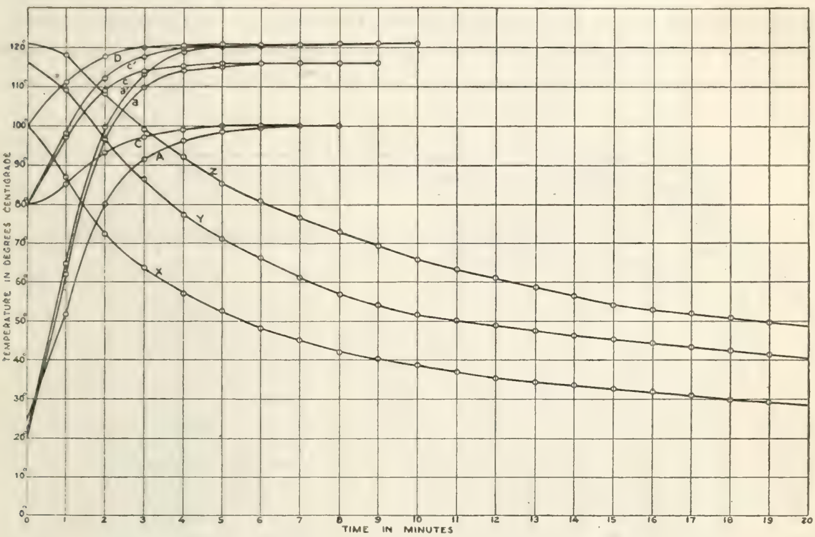

FIG. 15.—Experimental time-temperature curves for peas in No. 2 tin cans, starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curves are also given for cooling from different temperatures in water at 24° C. Curve for can starting: *A*, At 26° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a'*, at 21° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.; *D*, at 100° C. and processed at 121° C. Cooling curve for can starting: *X*, At 100° C. and cooled in water at 24° C.; *Y*, at 116° C. and cooled in water at 24° C.; *Z*, at 121° C. and cooled in water at 24° C.

HEAT PENETRATION.

The results of experiments on the rate of change of temperature in No. 2 cans of peas having different temperatures are shown in figure 15. These show that when cans are sealed at the various initial temperatures and processed at the same retort temperatures the heat penetration curves closely approach each other in the first four or five minutes of the process, and the difference in the length of time required to reach retort temperature amounts to only two or three minutes. The curves do not differ markedly from those for distilled water. The rate of temperature change in glass, although not shown here, is considerably slower than in the tin and agrees closely with that shown for string beans.

From the curves it is obvious that only a short exhaust is necessary for peas, two to four minutes being ample if sealing follows immediately. Emphasis must be laid on prompt sealing, however, as the air of the head space cools more rapidly than the material, and unless sealing is effected at once abnormal or too high pressures are developed during the processing and too low vacuums are obtained on cooling.

The cooling curves are of interest in that they show again how, in material like peas, the starch and other substances which are cooked out alter the viscosity of the liquor, causing the form of the cooling curves when temperatures are reversed to vary considerably from that of the heating curves. This is more marked in peas than in string beans. The curves also show how the viscosity is increased

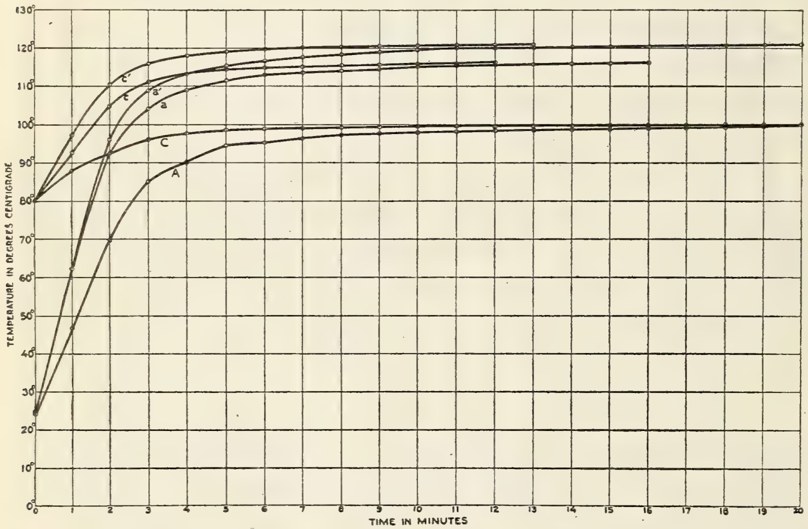

FIG. 16.—Experimental time-temperature curves for peas in No. 3 tin cans, starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curve for can starting: *A*, At 24° C. and processed at 100° C.; *a*, at 24½° C. and processed at 116° C.; *a'*, at 24½° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

by the higher processing temperatures. The viscosity will also be affected by the degree of maturity of the peas and the length of the processing period.

Figure 16 shows curves for the No. 3 can and illustrates how, because of the rapidity with which temperature changes occur, processing periods for No. 2 and No. 3 cans need differ but little; that is, four or five minutes.

There are several factors which will make the temperature change during processing vary slightly. If in any way a number of peas get broken the starch will come out of these more readily and will make the rate of change of temperature slightly slower. The more mature the peas the greater will be this effect. The proportion of peas to liquor will have a small effect also. If the proper quantity

of liquor has not been added the rate of change of temperature will be slightly slower. These differences are usually insignificant in common practice, in so far as such variations affect the length of the processing period.

TOMATOES.

PRESSURE STUDIES.

The tests upon tomatoes varied from those upon other substances in that the time-pressure curves were determined after different ex-

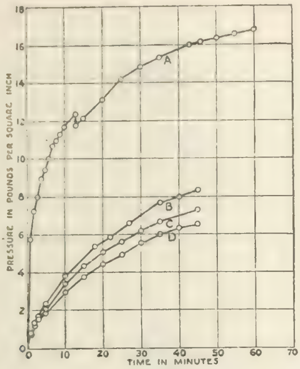

FIG. 17.—Experimental time-pressure curves for tomatoes in No. 2 tin cans, showing the effect of different periods of exhaust upon pressures developed during a processing period of 45 minutes at 100° C. Curve for can: *A*, Receiving no exhaust; *B*, exhausted for 2 minutes at 100° C., before processing; *C*, exhausted for 4 minutes at 100° C., before processing; *D*, exhausted for 6 minutes at 100° C., before processing.

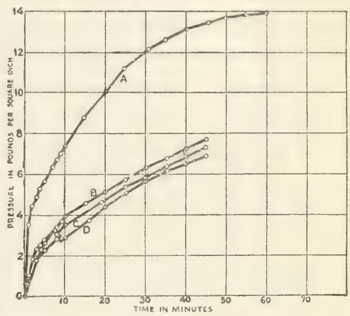

FIG. 18.—Experimental time-pressure curves for tomatoes in No. 3 tin cans, showing the effect of different periods of exhaust upon pressures developed during the processing period of 45 minutes at 100° C. Curve for can: *A*, Receiving no exhaust; *B*, exhausted for 2 minutes at 100° C., before processing; *C*, exhausted for 4 minutes at 100° C., before processing; *D*, exhausted for 6 minutes at 100° C., before processing.

haust periods. The tomatoes were peeled without scalding and weighed directly into the test cans, 550 grams being used in the No. 2 and 950 in the No. 3 cans. The initial temperature in all cases was between 22° and 25° C. The brass attachment was soldered to the can, which was then placed in the retort in the usual manner. In the case of the can receiving no exhaust, sealing was effected immediately and the test begun. The processing in all cases was at 100° C. In succeeding tests after placing the cans in the retort the steam was turned on and as soon as the retort temperature reached 100° C. (which was close to 30 to 45 seconds), time was taken and the cans exhausted for 2, 4, and 6 minutes, respectively. At the end of the exhaust period the can was immediately sealed, as previously described, and the time-pressure figures obtained.

Figure 17 shows the curves obtained for the No. 2 and figure 18 those for the No. 3 cans.

The outstanding feature of these curves is the fact that by far the greatest reduction in pressure during the 45-minute process period occurred as the result of the first two minutes of the exhaust. In the case of the No. 2 can this was a reduction of about 7 to 8 pounds per square inch during the first two minutes, which was lowered only about 1.8 pounds further by a 6-minute exhaust. The curves for the No. 3 can show the same thing, except that the maximum pressure developed in the can not exhausted was not so great. It is obvious that the temperature of the head space is the greatest factor in determining the vacuum and pressure, for the average of the can at the end of two minutes could not be high enough to account for the low pressure and high vacuum thus obtained. The effectiveness of a short exhaust, as in the case of peas, would be realized only by immediately sealing, as will be shown later by the results of vacuum tests on cans in lots which were exhausted in the steam box for the different exhaust periods and then removed and sealed at once.

VACUUM STUDIES.

The figures for the vacuum obtained in the cans used in the pressure tests which are of interest are presented in Table 8:

TABLE 8.—*Vacuum tests with tomatoes in No. 2 and No. 3 tin cans.*

Size of cans.	Temperature (°C.).		Time (minutes).		Barometer reading.		Vacuum (inches of mercury).
	Material at the start.	After cooling.	Exhaust.	Length of process.	At sealing.	After cooling.	
No. 2	24	16½	2	45	29.85	29.80	15
	23¼	17	4	45	29.80	29.73	16⅞
	23	19	6	45	29.39	29.39	17½
No. 3	25¼	22¾	2	45	29.86	29.85	15
	25	22	4	45	29.80	29.80	15
	24	21½	6	45	29.73	29.39	16

With the increase in exhaust there is slight increase in vacuum, which corresponds well with the figures on pressures, and they are found to be fairly high.

The average vacuum readings upon No. 3 cans in lots, exhausted for different periods in the steam box and then sealed in the mechanical sealing machine, were as follows:

- 1-minute exhaust .... 3 inches.
- 2-minute exhaust .... 3½ inches.
- 3-minute exhaust .... 4 inches.
- 4-minute exhaust .... 6½ inches.
- 5-minute exhaust .... 8 inches.

It is seen that these values are considerably below those in which the cans were sealed while still in the retort, and they illustrate how

the temperature of the head space at the time of sealing affects the vacuum. In this case the head space cooled considerably during the few seconds required to transfer the cans from the exhaust box to the sealing machine.

HEAT PENETRATION.

Figure 19 shows the experimental time-temperature curves for tomatoes in No. 2 cans starting at the initial temperature of 30° C. and processed at 100° for 20, 25, 30, and 35 minutes and then cooled in the air at room temperature, or about 20° C.

Though the cans were removed from the retort to the air, the temperature continued to rise for 25 to 30 minutes in the can processed for 20 minutes, and in the can processed for 35 minutes the rise continued for 20 to 25 minutes. If we assume sterilization processes to begin at 80° C., it will be seen that in the cans processed for 20 and 25 minutes the tomatoes at the center of the cans did not reach the sterilizing point at any time during the process. When processed 30 minutes the temperature remained above 80° C. for 25 to 30 minutes and when processed 35 minutes for about 45 minutes.

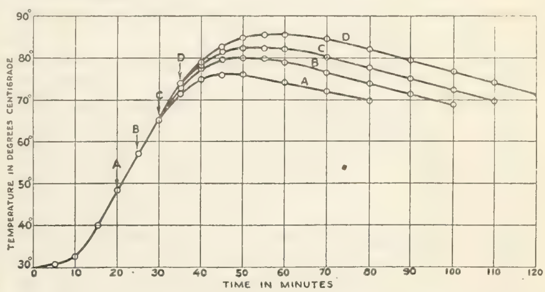

FIG. 19.—Experimental time-temperature curves for tomatoes in No. 2 tin cans, starting at a uniform temperature of 30° C., processed for 20, 25, 30, and 35 minutes at 100° C., and then cooled in air at ordinary room temperature. The arrows indicate when cans were taken from the retort. Curve for can processed: *A*, For 20 minutes; *B*, for 25 minutes; *C*, for 30 minutes; *D*, for 35 minutes.

These curves represent the averages for a number of tests. Owing to differences in maturity, difficulty in preparing uniform packs, and other factors, the time-temperature curves for tomatoes are found to be quite variable. It is believed, however, that the average conditions are fairly accurately illustrated by the above curves.

These curves show how very limited in usefulness is a time-temperature curve established under conditions that carry it entirely to the temperature of the retort. It gives very little idea of what temperature will be reached when processed for a definite time shorter than the time necessary to carry the center of the can to the temperature of the retort.

CORN.

PRESSURE STUDIES.

The corn used in these tests was gathered in prime table condition fresh from the field, husked and silked in the usual manner and cut from the cob "Maine style." It was then weighed and liquor added

to give the proportion of corn to liquor of 4 to 1. The corn was then precooked over steam with constant stirring until the temperature reached 80° C. It was then weighed into the No. 2 test cans, 550 grams being used in each case, brought to the desired uniform temperatures, sealed, the tests immediately begun, and the time-pressure curves determined. This procedure held for those cans sealed at 70° and 80° C. The procedure was the same with the cans sealed at 20° to $24\frac{1}{2}$° C., except that in one set of experiments the corn was precooked to 100° and in the other the corn was placed in the test cans without any precooking at all. Processing in all cases was for 120 minutes or thereabouts at the retort temperatures of 100°, 116°, and 121° C., respectively. Figure 20 shows the curves obtained in these tests.

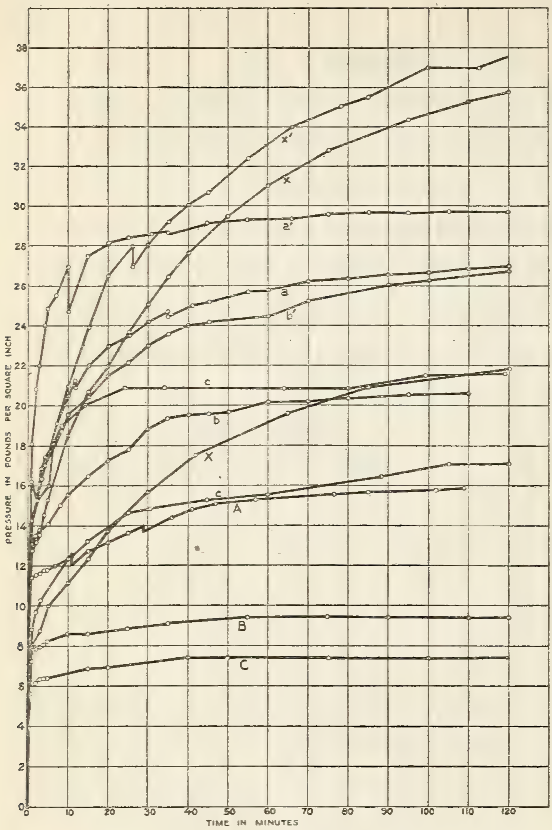

FIG. 20.—Experimental time-pressure curves for corn in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100°, 116°, and 121° C. Prepared "Maine style"; 550 grams of material used. Proportion of corn to liquor, 4 : 1. Curve for corn: *A*, Precooked at 100° C., sealed at $24\frac{1}{2}$° C., and processed at 100° C.; *a*, precooked to 100° C., sealed at $24\frac{1}{2}$° C., and processed at 116° C.; *a'*, precooked to 100° C., sealed at $24\frac{1}{2}$° C., and processed at 121° C.; *B*, precooked to 80° C., sealed at 70° C., and processed at 100° C.; *b*, precooked to 80° C., sealed at 70° C., and processed at 116° C.; *b'*, precooked to 80° C., sealed at 70° C., and processed at 121° C.; *C*, precooked to 80° C., sealed at 80° C., and processed at 100° C.; *c*, precooked to 80° C., sealed at 80° C., and processed at 116° C.; *c'*, precooked to 80° C., sealed at 80° C., and processed at 121° C.; *X*, with no precooking, sealed at 20° C., and processed at 100° C.; *x*, with no precooking, sealed at $24\frac{1}{2}$° C., and processed at 116° C.; *x'*, with no precooking, sealed at $24\frac{1}{2}$° C., and processed at 121° C.

These curves demonstrate the following facts:

(1) The pressure rises almost immediately to a high point when the steam is turned on, as a result of the sudden expansion of the air of the head space. After the first minute the rise is more gradual, the rate corresponding largely to the rate of temperature change in the corn.

(2) Relatively low pressures are obtained when the higher sealing temperatures are employed.

(3) Great pressures are developed when the corn is not precooked, owing to the swelling of the starch and to the included air.

(4) The continued rise in pressure due to the liberation of gases, while shown, is partially masked, for the reason that the temperature at the center of the can did not reach the retort temperature during the processing period.

(5) The rate of rise in pressure during processing is greater at the higher processing temperatures.

(6) The maximum pressures are all somewhat below the theoretical and somewhat (except in the case of those not precooked) above that for water alone, in which the pressures are considerably below the theoretical.

VACUUM STUDIES.

The vacuum readings on cans used in the tests sealed at 70° and 80° C. are shown in Table 9.

TABLE 9.—*Vacuum tests with corn in No. 2 tin cans.*

Temperature (°C.).			Length of process (minutes.)	Barometer readings.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.		At sealing.	After cooling.	
70	100	22¾	120	30.05	29.99	12
	116	25	110	29.99	29.86	9⅛
	121	17½	121	30.08	29.92	9⅞
80	100	25	140	29.56	29.62	15⅝
	116	24¾	120	29.99	30.01	14⅛
	121	24¼	120	30.01	30.05	13¾

As in tests upon other materials the higher the processing temperature the lower the vacuum, owing to the liberation of gases during processing. Repeated experiments have shown that for the same reason the longer the processing period the smaller the vacuum. All results are below the theoretical figures.

Vacuum readings with corn in No. 2 cans sealed in lots at various temperatures and processed intermittently for 1½ hours at 100° C. gave the figures shown in Table 10.

Concussion tests with corn prepared as in these vacuum tests showed that the susceptibility to denting gradually increased with the rise of sealing temperature. The figures obtained are also shown in Table 10.

TABLE 10.—*Vacuum readings and concussion tests with corn in No. 2 tin cans.*

Sealing temperature (°C.).	Vacuum (inches of mercury).	Fall of weighted can (cm.).
22		8.0
45 to 50	3	8.9
55 to 60	7.6	8.6
65 to 70	11	7.6
75 to 80	14.6	6.4
95 to 100	21.2	5.0

These figures seem to indicate that sealing at initial temperatures as high as 85° C., or even higher, may be practiced without great danger of serious denting or collapsing of No. 2 tin cans.

Various influences tend to affect the results in individual cans—the weight of the tin plate from which they are made, the perfection in form, etc. The data shown in Table 10 represent an average for one lot of cans and are given for what they are worth.

HEAT PENETRATION.

The time-temperature relation for a No. 2 can of corn started at various initial temperatures, processed for various lengths of time under different retort conditions, and cooled in air and in water are given below.

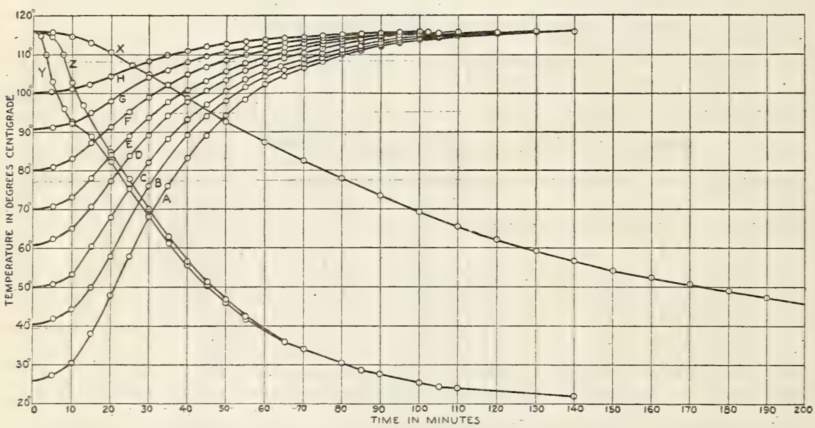

FIG. 21.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at different uniform temperatures and processed at 116° C. Proportion of corn to liquor, 4 : 1. Curves are also given for cooling in air at 26° C. and for cooling in water at 20° C., one curve of which is for corn of heavier consistency. Curves for can starting: *A*, At 26° C.; *B*, at 40½° C.; *C*, at 50° C.; *D*, at 61° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90½° C.; *H*, at 100° C.; *X*, at 116° C. and cooled in air at 26° C.; *Y*, at 116° C. and cooled in water at 20° C.; *Z*, at 116° C. and cooled in water at 20° C., the consistency of the corn being heavier than that represented in curve *Y*.

Figure 21 gives the experimental heat-penetration curves for No. 2 cans of corn starting at various temperatures and processed at 116° C.

These show how differences in initial temperatures modify the form of the time-temperature curve. Theoretically, the temperature at the center of the can should reach the temperature of the retort in the same time for any initial temperature, but in these tests the cans starting at the higher initial temperature actually reached the temperature of the retort in a slightly shorter time. This would seem to be due to some convection occurring in corn of this consistency.

Thompson (9) has given a formula by means of which from a single experimentally determined heat-penetration curve one may

calculate corresponding curves for the different initial temperatures. A series of curves calculated by means of this formula, using one of the above experimental curves, will be found to agree closely with the other experimental curves starting at different initial temperatures. The formula is valuable in calculating curves of this sort in that it saves much time and labor.

Figure 21 also shows experimental curves for cooling both in air and in water. Attention is directed to the very slow rate of cooling in air as compared with that of cooling in water. The form of the curves for cans cooled in water are of special interest. In the case where the proportion of corn to liquor is the same as in the heating curve (that is, 4 to 1) the temperature falls very rapidly at first, but later the form of the curve becomes more regular and eventually coincides with the second curve.

In the corn of heavy consistency the lag at the beginning is greater, and the temperature falls more slowly. If the head space in the corn

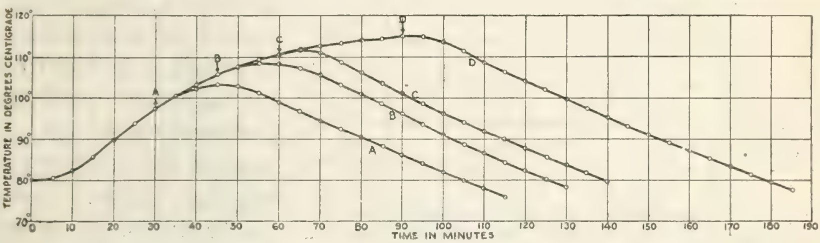

FIG. 22.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C.; processed for different time periods at 116° C.; and cooled in air at ordinary room temperature. Proportion of corn to liquor, 4 : 1. The arrows indicate when cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 90 minutes.

of heavy consistency is increased, the cooling will be faster and the curve will resemble closely that for the can of corn having a normal consistency. At temperatures above 100° C. and where the head space permits there seems to occur a condensation of steam in the head space, resulting in a simple sort of distillation which quickly reduces the temperature below the boiling point of water. The reduction of the pressure in the head space causes ebullition and a consequent stirring of the material, resulting in a rapid fall of temperature.

These results emphasize again the fact that cooling curves for food materials are practically never the exact reverse of the heating curves, even when temperatures of the surrounding medium are reversed.

Figure 22 shows experimental curves for No. 2 cans of corn sealed at 80° C. and processed at 116° for 30, 45, 60, and 90 minutes and then cooled in the air at 20° to 25° C.

These curves represent individual tests and hence probably vary somewhat from the average. They show how the temperature at the center of the can continues to rise after taking from the retort for from 5 minutes in the case of the can processed for 90 minutes to 15 minutes in the can processed for 30 minutes. They show, further, the length of time the corn remains above critical temperatures for sterilizing purposes. For instance, the temperature is seen to remain above 100° C. for 20 minutes when the processing is continued for 30 minutes and remains above 100° C. for 95 minutes when processed for 90 minutes. These values obviously would be different for curves starting at different initial temperatures. The curves give a definite idea, however, of the rate and the nature of the temperature changes when corn is processed for various periods and then air cooled. They show how very limited in value such curves as are illustrated in figure 21 may be, for they are a record of a continuous processing at a definite temperature until the temperature of the can reaches the temperature of the retort. Since with corn in actual practice the processing period is less than the time necessary for the can to reach the temperature of the retort, curves such as are shown in figure 21 give an actual record only so long as the can is in the retort, but tell nothing beyond that point. It is important to have a record of the temperature after the can is removed from the retort, which can be obtained best from curves made under conditions of actual practice. Since the behavior of the temperature of the contents of the can after removal from the retort varies with the processing period and with the cooling conditions, it makes the calculation of the record of one processing from another of a different length very difficult.

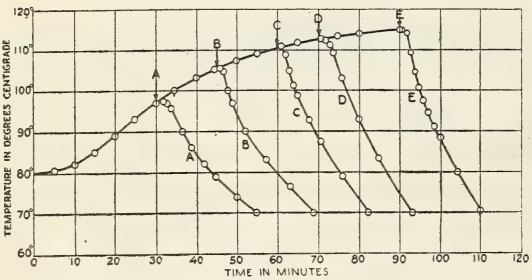

FIG. 23.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C., processed for different periods of time at 116° C., and cooled in water at about 25° C. Proportion of corn to liquor, 4 : 1. The arrows indicate when cans were taken from the retort and put into water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 70 minutes; *E*, for 90 minutes.

Figure 23 shows the time temperature curves for No. 2 cans of corn starting at 80° C.; processed at 116° for 30, 45, 60, 70, and 90 minutes, and then cooled in water.

When the cans are removed from the retort and placed in cold water the rise in temperature is almost immediately stopped and the cooling curves drop rapidly. In corn, therefore, when the cans are

cooled in water the maximum temperatures are usually reached at the time when the cans are placed in the water. When cooling immediately in water is practiced one is able to control rather definitely the amount of cooking the corn will receive unless it is of very heavy consistency, when curves such as those shown in figure 21 may be of very much value.

The curves show that when the can is started at 80° C. and processed for 30 minutes at 116° the center of the can of corn never reaches 100° C. when cooled in water. When processed for 45 minutes it remains above 100° C. about 13 minutes, about 30 minutes when processed for 60 minutes, about 42 minutes when processed for 70 minutes, and about 60 minutes when processed 90 minutes. It remained above 110° C. for about 15 minutes when processed for 70 minutes, and for approximately 35 minutes when processed for 90 minutes.

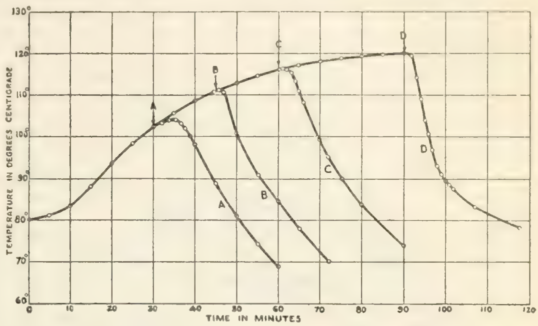

Fig. 24.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C., processed for different time periods at 121° C., and cooled in water at 23° to 26° C. Proportion of corn to liquor, 4 : 1. The arrows indicate the time when cans were removed from the retort and placed in water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 90 minutes.

Differences in initial temperatures and in the consistency of the corn, of course, would vary these figures.

Figure 24 shows similar curves for corn handled in the same way as in the above tests, except that the retort temperature of 121° C. was employed.

In the discussion of results obtained with string beans and peas the relationship of the time-temperature and the time-pressure curves was pointed out. In comparing the time-pressure and time-temperature curves in sweet corn it is seen that the pressure rises very rapidly during the first minute or two of the processing period, owing to the heating of the head space. On the other hand, the temperature at the center of the can is still little changed, and the heat certainly has penetrated only slightly into the material. After several minutes, however, the pressure rises more gradually, corresponding closely to the rate at which the heat penetrates into the material. It does not correspond exactly to this, however, for there is a continuous rise of pressure so long as the processing is continued, this being more pronounced with the higher processing temperatures.

SWEET POTATOES.

PRESSURE STUDIES.

In the tests upon sweet potatoes the material used was in the form of "pie stock," prepared by washing the potatoes, steaming until done, peeling, and then passing them through a food chopper to give a uniform consistency. The material was then weighed into the test cans, 600 grams being used in the No. 2 and 1,000 grams in the No. 3 can. After the can and contents were brought to a uniform desired temperature, the tests were performed in the usual way. Figure 25 shows the time-pressure curves for sweet potatoes in No. 2 cans sealed at the initial temperatures of 25°, 70°, and 80° and processed for 120 minutes at 116° C., and figure 26 shows the curves for No. 3 cans tested in the same manner.

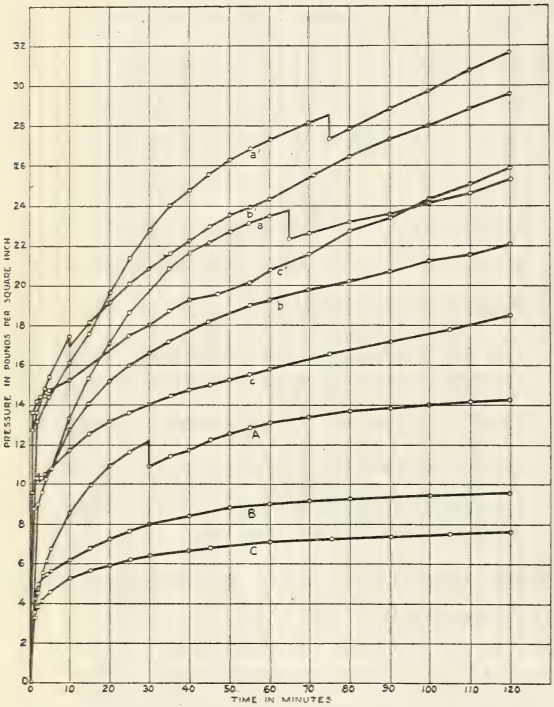

FIG. 25.—Experimental time-pressure curves for sweet potatoes in the form of pie stock in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100° C., 116° C., and 121° C. Curve for can sealed: *A*, At 25° C. and processed at 100° C.; *a*, at 25° C. and processed at 116° C.; *a'*, at 25° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The outstanding features of the curves for sweet potatoes are much the same as for sweet corn.

The initial sudden rise in pressure does not reach so high a point as in the corn, owing to smaller head space. That this sudden rise is due to the expansion of the air of the head space is clearly shown by the fact that the curves following this initial rise begin their more gradual ascent at approximately the same point, later diverging according to the sealing temperature employed.

The rise in pressure continues throughout the processing period, corresponding in some degree to the rate of temperature change within the can, but not due entirely to this. The pitch of the curves

during this latter half of the processing period indicates that some influence other than increase of internal temperature is in operation. That this is the case is shown in the vacuum figures given later.

The maximum pressures attained vary in both directions from the theoretical, some being higher and others lower. The variable factors of sudden bulging and gradual distention of the cans, liberation of gases, etc., contribute to this result and account for it. The swelling of the starch can hardly account for any increase in pressure, as the material was well cooked before it was put into the cans.

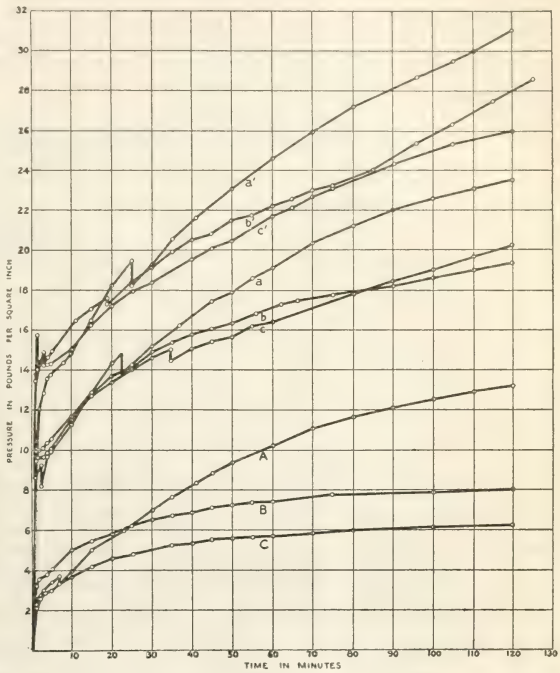

FIG. 26.—Experimental time-pressure curves for sweet potatoes in the form of pie stock in No. 3 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100°, 116°, and 121° C. Curve for can sealed: *A*, At 25° C. and processed at 100° C.; *a*, at 25° C. and processed at 116° C.; *a′*, at 25° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b′*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c′*, at 80° C. and processed at 121° C.

The processing period used in these tests is longer for the higher temperatures than is commonly employed, but the maximum pressures for any period of 120 minutes or less will be shown on these curves, for when the steam in the retort is cut off the pressures fall almost immediately.

As pointed out in considering the results on string beans, the actual strain on cans at any time during the process may be found by subtracting the retort pressure from the pressure indicated for that time in the curve. The strain on the can is greatly increased when the retort pressure is released, but the greatest strain is felt when the pressure in the retort reaches zero. This amounts to only about 3 to 5 pounds less than the maximum pressure indicated in the curves, depending upon the temperature of sealing, the processing temperature, the bulging of cans, the rate of release of retort pressure, etc. If the retort pressure should be completely released instantaneously

the full maximum strains indicated in the curves would be exerted on the cans from within, but the gradual release of pressure allows some lessening from the maximum strain indicated. When the processing is done at 100° C. the maximum pressures indicated in the curves represent the actual strains on the cans. These curves illustrate again the necessity of sealing at relatively high temperatures.

VACUUM STUDIES.

Table 11 presents the results of vacuum readings on the No. 3 cans sealed at 70° and 80° C. used in the above tests when cooled to room temperature.

TABLE 11.—*Vacuum tests with sweet potatoes in No. 3 tin cans.*

Temperature (°C.).			Processing period (minutes).	Barometer readings.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.		At sealing.	After cooling.	
70	100	10⅝	120	30.30	30.17	13⅛
	116	21	120	30.25	30.19	11
	121	13½	120	29.77	29.89	10⅝
80	100	16	120	29.98	29.86	14
	116	9	120	29.87	30.29	13½
	121	12	120	30.29	30.45	9

The figures in Table 11 do not differ essentially from those obtained with corn. They are below the theoretical, and there is the decrease of vacuum with the higher processing temperatures.

Concussion tests, as described under methods and apparatus, though not altogether satisfactory in point of uniformity of results, show that there is a relation between the vacuum and the susceptibility of the can to bruising in handling. The figures seem to indicate that in ordinary practice No. 2 cans may be safely sealed at as high as 85° C. Above 90° they are quite readily dented, and they usually collapse spontaneously when sealed between 95° and 100° C. Tests for the No. 3 cans show that they are much more easily bruised than the No. 2 cans where the vacuum is equal in the two cases. The results seem to indicate that it is scarcely safe to seal No. 3 cans very much above 80° C. Bruising occurs rather readily above 85° and the cans may collapse spontaneously at 90° C. or above, depending upon their strength.

HEAT PENETRATION.

The material used for the time-temperature studies in sweet potatoes was prepared in the same manner as that used in the foregoing experiments on pressure and vacuum. The rates of temperature changes in No. 2 cans of sweet potatoes, starting at different tem-

peratures and processed at 116° C., are shown in figure 27. Experimental curves for cooling both in air and in water are likewise given.

The heating curves are similar to those for corn, though there is a greater lag at the start and the temperature reached in a given unit of time is materially lower than in the corn. In other words, as has been previously shown, the rate of temperature change is slower in sweet potatoes than in corn, as ordinarily handled. Regardless of initial temperature, the temperature of the retort is reached in the same time.

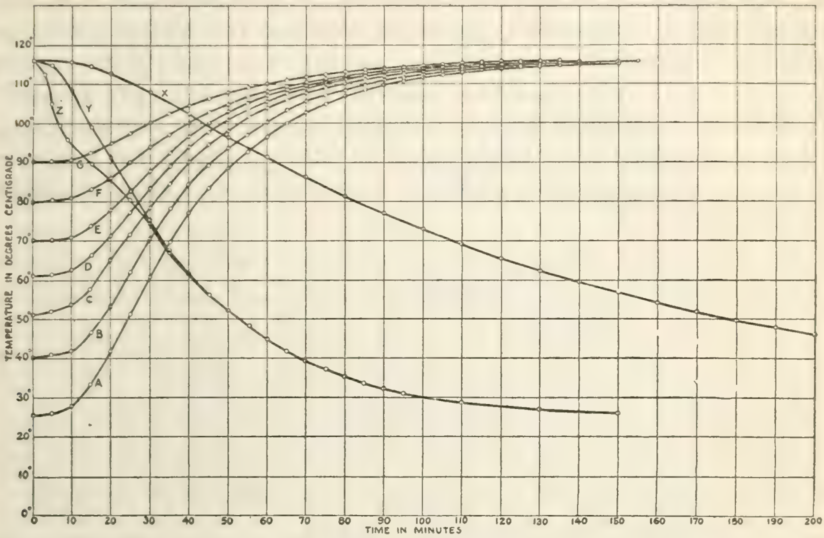

FIG. 27.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures and processed at 116° C. Curves are given also for cooling in air and in water at 26° C. A curve showing the effect of differences in head space upon the rate of cooling in water is included. Curve for can starting: *A*, At 25½° C.; *B*, at 40° C.; *C*, at 51° C.; *D*, at 61° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90° C.; *X*, at 116° C. and cooled in air at 26° C.; *Y*, at 116° C. and cooled in water at 26° C., head space very small; *Z*, at 116° C. and cooled in water at 26° C., head space three-eighths of an inch.

Here, also, as in the case of the curves for corn, the formula given by Thompson (9) for the calculation of curves for different initial temperatures from a single experimental curve is applicable, and the formula given by Bigelow and his collaborators for calculating curves for cans of different sizes may be made use of in time-temperature studies with sweet potatoes.

As has been pointed out in the consideration of time-temperature relations in corn, curves which require a longer time to reach retort temperature than that necessary to effect sterilization of the product are not safe guides in the determination of proper processing periods, inasmuch as when cooled in air and, in the case of sweet

potatoes, also when cooled in water, there is a continued rise of temperature at the center of the can for an indefinite period. Accurate information for this purpose must be obtained by processing for different periods and cooling in air and water, for which purpose the formulas of Thompson and of Bigelow are scarcely applicable.

The cooling curves are of interest in that they illustrate clearly the desirability of cooling cans of sweet potatoes in water. Owing to the high percentage of sugar in the sweet potato, caramelization is very pronounced when the processing temperatures are long continued, and it is desirable, therefore, that the processing period be carefully controlled. Air cooling, as shown by the curves, results in a slow fall of temperature, and the cooking is long continued. It must be rememered, however, that in slow cooling the sterilizing effect is continued for a longer period. How promptly the temperature falls when the can is cooled in water is illustrated by the other cooling curves.

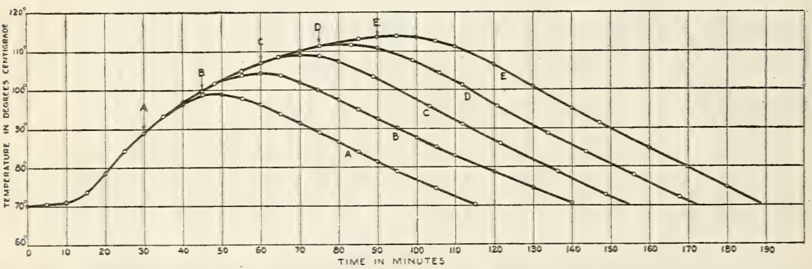

FIG. 28.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in air at ordinary room temperature. The arrows indicate when the cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 75 minutes; *E*, for 90 minutes.

Special attention is directed to the form of the curves for water cooling during the first 15 minutes. In the one case the curve is quite regular, while in the other there is a sudden drop in the curve, which later becomes more regular and eventually coincides with the first. The only difference in the conditions under which these tests were performed was that in the first case the can had a very small head space, while in the other a head space of about three-eighths of an inch was allowed. A similar condition was pointed out in the discussion on the cooling curves for corn where, also, the consistency was shown to be a factor. Owing to the heavy consistency and the necessity of filling the can almost completely, the cooling curves of sweet potatoes are more nearly the exact opposite of the heating curves than in any other substance tested.

In figure 28 are shown the experimental time-temperature curves for No. 2 cans of sweet potatoes, starting from a uniform initial tem-

perature of 70° C., processed at 116° for 30, 45, 60, 75, and 90 minutes, and then cooled in air at 26° C.

In the can processed for 30 minutes the temperature continues to rise for 20 minutes. A gradual reduction in the time during which the succeeding curves continued to rise is noted, the can processed for 90 minutes continuing only 5 minutes. In 30 minutes of processing the can did not reach 100° C. When air cooled the can processed for 45 minutes remained above 100° C. for 30 minutes; when processed for 60 minutes it remained above that point for a little over 50 minutes; when processed for 75 minutes, for about 70 minutes; and when processed for 90 minutes it remained above 100° C. for nearly 90 minutes. The significance of these figures is apparent.

Figure 29 shows curves obtained under like conditions, except that the cooling was done in water at 17° C.

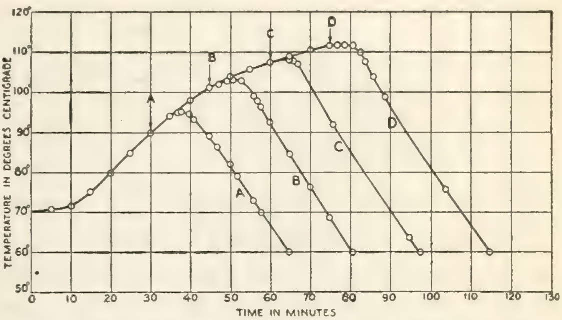

Fig. 29.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in water at about 17° C. The arrows indicate when the cans were taken from the retort and placed in water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 75 minutes.

It will be noted that with sweet potatoes, even in water cooling, the temperature continues to rise for a little while, but the time is much reduced over what was obtained with air cooling. Within the range of these experiments the rise continued only from 5 minutes in the case of the can processed for 75 minutes to 8 minutes in the can processed for 30 minutes.

As in the preceding figure, the temperature in the can processed for 30 minutes did not reach 100° C. at all; that processed for 45 minutes remained above 100° C. for about 12 minutes; that processed for 60 minutes for about 28 minutes; and that processed for 110 minutes for about 45 minutes.

Comparing these figures with the figures for air cooling, we find that the time during which cooking continues after 100° C. is reached is reduced by 18 minutes in the can processed for 45 minutes and by 25 minutes in the can processed for 110 minutes.

How one is able to control the cooking and thus prevent in a measure the caramelization of the material by water cooling of the cans is clearly illustrated.

Figure 30 shows the experimental time-temperature relations for No. 3 cans of sweet potatoes starting at the initial uniform tempera-

ture of 70° C.; processed at 116° C. for 30, 45, 60, 70, and 90 minutes, respectively, and then cooled in air.

The salient differences between these curves and those for No. 2 cans lie in the fact that the heat at the center of the No. 3 can con-

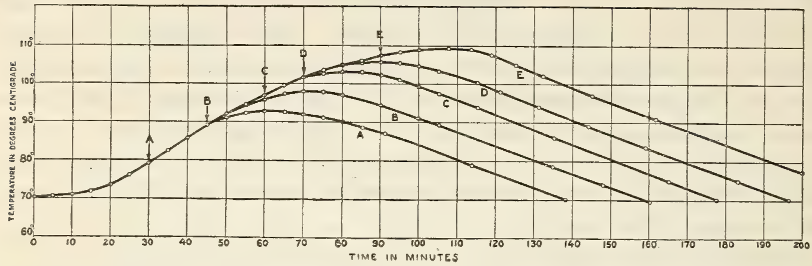

FIG. 30.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in air at ordinary room temperature. The arrows indicate when the cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 70 minutes; *E*, for 90 minutes.

tinues to rise for a longer time than in the No. 2 can, but the maximum temperatures attained are lower and the time the temperature remains above 100° C. in the various tests is materially less. This is due, of course, to the very slow rate of temperature changes in the sweet potato. The difference in time during which they remain above 80° C. is small, being slightly longer in the case of the No. 3 can.

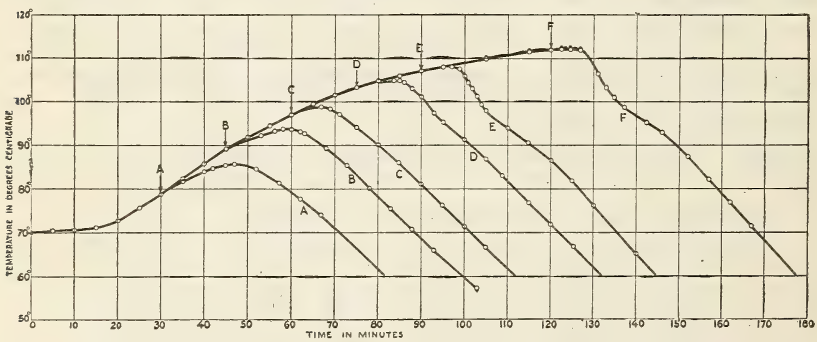

FIG. 31.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in water at 16° to 20° C. The arrows indicate when the cans were taken from the retort and placed in water. Curve for can processed: *A*, For 30 minutes and cooled at 19° C.; *B*, for 45 minutes and cooled at 20° C.; *C*, for 60 minutes and cooled at 17° C.; *D*, for 75 minutes and cooled at 19° C.; *E*, for 90 minutes and cooled at 16° C.; *F*, for 120 minutes and cooled at 18° C.

Figure 31 shows the experimental curves for water cooling of No. 3 cans handled in the same way as the above.

As in the case of the No. 2 cans handled similarly, the temperature continues to rise after the cans are placed in cold water, but

the length of time is increased. In water cooling, even when processed for 60 minutes, the temperature never reaches 100° C. In addition to the facts brought out in the discussion on water-cooled No. 2 cans, the form of the cooling curves for No. 3 cans processed for the longer periods is of interest as illustrating again the effect of condensation of steam within the head space and the consequent rapid fall of temperature, which has been earlier considered. These, with the preceding curves, are of great practical value in determining the length of the processing period of sweet potatoes.

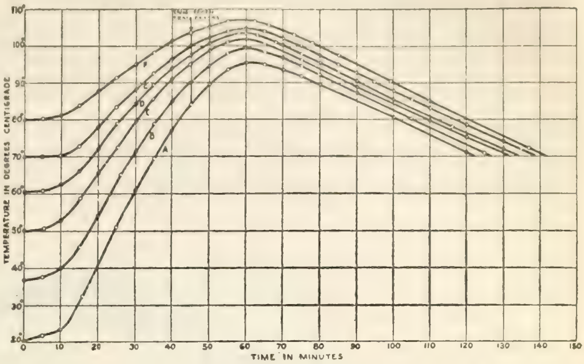

FIG. 32.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures, processed for 45 minutes at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 20° C.; *B*, at 37° C.; *C*, at 50° C.; *D*, at $60\frac{3}{4}$° C.; *E*, at 70° C.; *F*, at 80° C.

Figure 32 shows the experimental curves for sweet potatoes in No. 2 cans, starting at the different initial temperatures, processed for 45 minutes at 116° C., and cooled in air. Figure 33 shows the same for the No. 3 can, except that the processing period is 60 minutes.

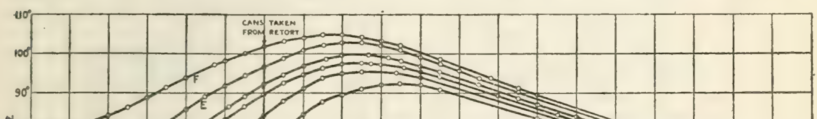

FIG. 33.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at different uniform temperatures, processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At $24\frac{1}{2}$° C.; *B*, at $38\frac{1}{4}$° C.; *C*, at $51\frac{1}{2}$° C.; *D*, at 60° C.; *E*, at $70\frac{1}{4}$° C.; *F*, at 80° C.

These curves show the effect which different initial temperatures have upon the maximum temperatures attained during a single definite processing period, and they furnish a definite picture of the

time-temperature changes which obtain under practical working conditions. They emphasize again the fact brought out in the earlier consideration of this subject that in substances where the processing period is shorter than the time required for the center of the can to reach the temperature of the retort, the entire heat penetration curves, like those shown in figure 27, are not safe guides for determining the length of the processing period and that the entire cooling curves as well do not illustrate working conditions. They show, further, that the maximum temperatures actually attained vary less with differences in initial temperature than might be expected from

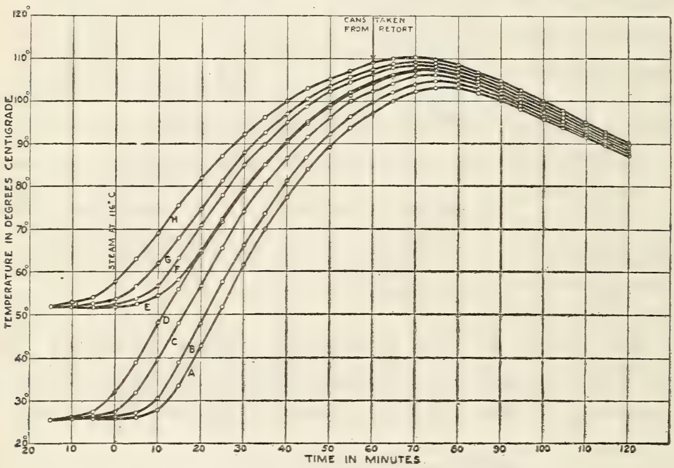

FIG. 34.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures, exhausted for different time periods at 100° C., processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 26° C. and receiving no exhaust; *B*, at 26° C. and exhausted for 5 minutes; *C*, at 26° C. and exhausted for 10 minutes; *D*, at 26° C. and exhausted for 15 minutes; *E*, at 52° C. and receiving no exhaust; *F*, at 52° C. and exhausted for 5 minutes; *G*, at 52° C. and exhausted for 10 minutes; *H*, at 52° C. and exhausted for 15 minutes.

the curves in figure 21. Although the entire curve must be given consideration, certainly the most important part of this curve is when it is at its maximum. The fact that the maximum temperatures vary so very much less than the initial temperatures helps to explain why often such uniform results are obtained where considerable variation in initial temperatures exist. For instance, it will be seen, in the case of the No. 2 cans, that in cans starting at initial temperatures differing as much as 30 degrees, the maximum temperatures reached may not vary by more than 4 or 5 degrees, and in the case of the No. 3 can only slightly more.

The actual temperature reached and the length of time the material at the center of the can remained above any definite point may be readily observed.

Curves of this sort would vary in form and in the maximum temperatures reached, of course, with different retort temperatures and with the length of the processing periods.

In figures 34 and 35 are shown the effect of different exhaust periods upon the time-temperature curves for No. 2 and No. 3 cans of sweet potatoes sealed at different temperatures, processed for 60 minutes, and cooled in air. Exhausting was done in the steam box for 5, 10, and 15 minutes at 100° C.

The effect of exhaust upon the form of the curves and the maximum temperatures reached are clearly shown, and little comment is required. It may be pointed out that in the case of the No. 2 cans the temperature in all cases went above 100° C.; 15 minutes' exhaust resulted in the temperature remaining above 100° C. for 18 to 20 minutes longer than in those receiving no exhaust. The maximum temperatures varied by 4 or 5 degrees.

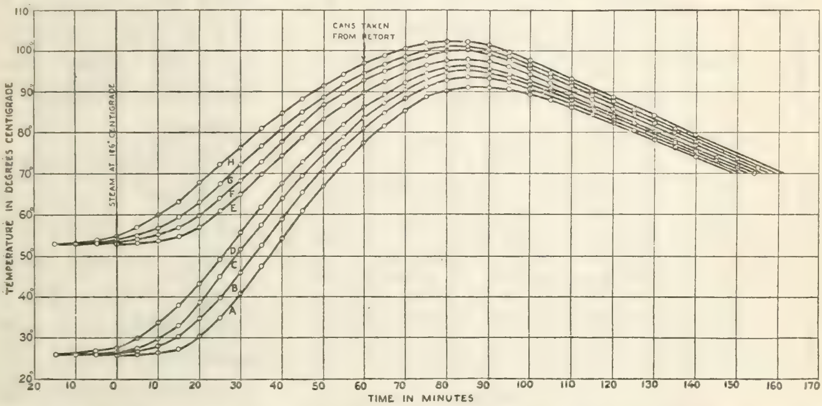

FIG. 35.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at different uniform temperatures, exhausted for different time periods at 100° C., processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 26° C. and receiving no exhaust; *B*, at 26° C. and exhausted for 5 minutes; *C*, at 26° C. and exhausted for 10 minutes; *D*, at 26° C. and exhausted for 15 minutes; *E*, at 53° C. and receiving no exhaust; *F*, at 53° C. and exhausted for 5 minutes; *G*, at 53° C. and exhausted for 10 minutes; *H*, at 53° C. and exhausted for 15 minutes.

It is noted also that the time-temperature curve for the No. 2 can starting at 26° C. and exhausted for 15 minutes coincides almost exactly with that for the can sealed at 52° with no exhaust.

As is to be expected, the differences are greater in the case of the No. 3 cans. In only three of the cans did the temperature at the center of the containers reach 100° C. The maximum temperatures reached in cans exhausted for 15 minutes varied from those receiving no exhaust by 4 or 5 degrees, and, as in the case of the No. 2 can, the effect of the 15-minute exhaust on the increase in the length of time the temperature remained above a definite point amounted to 18 or 20 minutes.

SPINACH.

Owing to the limited quantity of raw material for use, the data upon spinach are incomplete. The figures which were obtained, however, are considered of sufficient value to warrant their use, and they are therefore presented for what they are worth.

The spinach was gathered fresh from the field, carefully trimmed, washed, and then blanched for two minutes in boiling water. It was then placed in the test cans, brought to the required uniform temperature, and the tests begun.

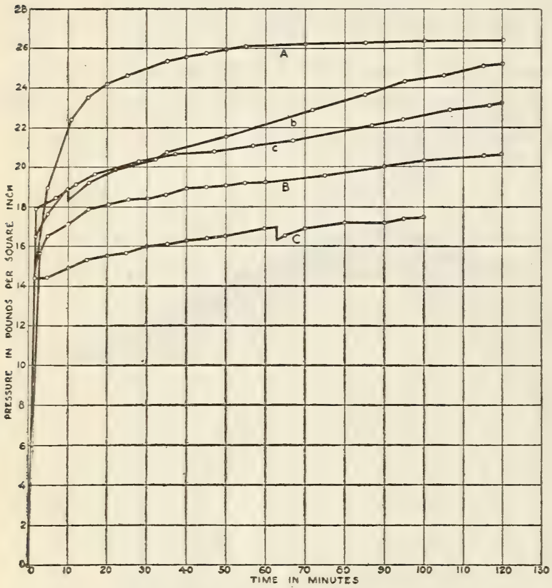

FIG. 36.—Experimental time-pressure curves for spinach in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 116° and 121° C. Curve for can sealed: *A*, At 18¾° C. and processed at 116° C.; *B*, at 70° C. and processed at 116° C.; *b*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 116° C.; *c*, at 80° C. and processed at 121° C.

PRESSURE TESTS.

Figure 36 shows the curves for pressure tests with spinach in No. 2 cans, conducted as with other food materials already described.

The salient features of these curves do not differ from those shown in the tests upon corn. As in corn, there is a very sudden rise in the pressure curves, due to the sudden expansion of the air in the head space, after which the increase in pressure is more gradual. The continued increase in pressure is due apparently to the liberation of gases. In one case this was found to be still taking place at the end of more than three hours. Only one curve is given for cans sealed at low temperatures and none at all for the processing temperature of 100° C. That great reduction in pressure is obtained, however, by sealing at the higher temperatures is shown.

VACUUM STUDIES.

The vacuum tests upon spinach, while incomplete, as in the case of the pressure, bring out the following facts clearly:

(1) The vacuum obtained by sealing the spinach into the can at the desired temperature and then cooling immediately always gives a higher vacuum read-

ing than is obtained when the reading is made following processing. In the light of the preceding consideration of the liberation of gases during processing, this result is to be expected.

(2) The longer the processing period, the lower the vacuum obtained.

HEAT PENETRATION.

Figure 37 shows the heat-penetration curves for No. 2 cans of spinach starting at 70° and 80° C., processed for different periods at 116° and cooled in water. The entire heating curve is also shown for the No. 2 can, starting at 20° C. and processed at 116° until the retort temperature was reached.

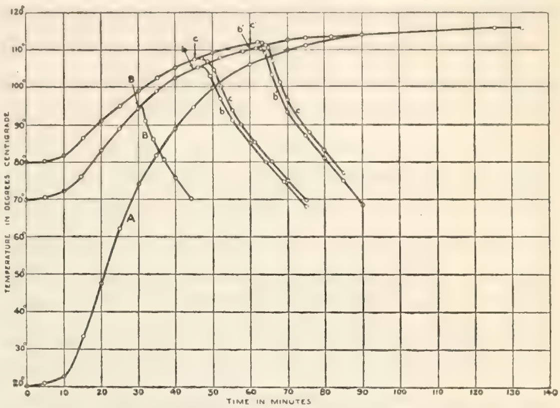

Fig. 37.—Experimental time-temperature curves for spinach in No. 2 tin cans, starting at different uniform temperatures, processed for different time periods at 116° C., and cooled in water at 23° to 24° C. The arrows indicate when the cans were taken from the retort and placed in water. *A*, Entire heat-penetration curve for can starting at 20° C. and processed at 116° C. Curve for can starting: *B*, At 70° C. and processed for 30 minutes; *b*, at 70° C. and processed for 45 minutes; *b'*, at 70° C. and processed for 60 minutes; *c*, at 80° C. and processed for 45 minutes; *c'*, at 80° C. and processed for 60 minutes.

These curves are entirely similar to those obtained for sweet corn, though the rate of temperature change is slightly faster.

By comparison of these curves with the entire curve, starting at 20° C., it will be seen that after 60 minutes of processing the temperature at the center of the can starting at 80° is only 6 degrees above that of the can starting at 20°, and in the case of the can starting at 70° C. it is only 4 degrees higher.

When the can is cooled in water the temperature at the center of the can continues to rise for one or two minutes only and then falls rapidly. It is obvious, therefore, that here also, as in the case of corn and sweet potatoes, the cooking of the material in the can may be closely controlled by cooling in water.

PRESSURE AND VACUUM IN GLASS CONTAINERS.

The studies upon pressure and vacuum as applied to foods in glass have not been completed. As is well known, the development of pressures in glass containers is accompanied by danger and loss, owing to liability to breakage, and this is avoided in present practice by partially sealing at first and then completing the sealing operation after the processing has been done. The escape of air, while nearly or entirely complete in most cases, may be slightly restricted

in others, so that small pressures are to be expected. The amount of pressure actually developed will depend, of course, upon the perfection in construction of the container, the thickness and quality of the rubber rings, and the pressure exerted by the device holding the cap in place. These pressures are practically negligible.

Investigations upon the resistance of rubber rings and other sealing equipment designed for use with glass are receiving attention at the hands of the manufacturers of glass containers, and Bitting (6) has recently published the partial results of work upon this subject.

The fact that with some substances an undesirable metallic taste is imparted to the food by the tin makes the use of glass containers desirable; and knowledge of the fact that, with fruits especially, delicate flavors may be retained in the product by completely sealing the jar before processing and then cooking at temperatures below 100° C. will doubtless lend impetus to investigations of this sort and result in the manufacture of glass containers better suited than those now employed for use where pressures are developed.

On account of their rigidity the pressures and vacuums obtained in glass jars hermetically sealed before processing should give figures more closely approaching the theoretical values than those obtained with tin. Owing to the fact that, in present practice, most, if not all, of the air escapes during the processing, the vacuum obtained is close to the theoretical value when the jars are sealed immediately at the end of the processing period. Unless complete sealing is effected at once, however, air is drawn into the jar and the vacuum obtained is less, depending upon the rate of cooling and the length of time elapsing before the jar is sealed.

SUMMARY.

(1) In tin cans containing various quantities of water, changes in pressure vary somewhat from the calculated values, owing to the distortion of the can under the changed conditions.

(2) With water the rate of change of pressure and the rate of change of temperature at the center of the can agree closely and are very rapid where the external medium is water and very slow where the external medium is air.

(3) With food materials in which a free liquid fills the interspaces the rate of change of pressure and of temperature is very rapid; but while the maximum temperature is reached promptly, the maximum pressure, on the other hand, is never reached during the ordinary processing periods, the pressure continuing to rise slowly as long as the high retort temperatures are maintained.

(4) In cans filled with material of heavy consistency, the rate of change of temperature at the center of the can is very slow. In contrast with this, the rate of change of pressure is very rapid at

first and then becomes slower after the first few minutes. An equilibrium of pressure apparently is never reached, since in experiments where processing was continued for several hours the pressure continued to rise as long as the retort temperature was maintained.

(5) The continued increase in pressure long after an equilibrium of temperature is reached has been explained as due to the decomposition of the food material with the consequent liberation of gases. The setting free of hydrogen as a result of the action of the acids of the material upon the metal of the can would give this result, and doubtless it does with some acid fruits, but experiments with vegetables seem to indicate that this is not the sole cause of the increase in pressure.

(6) In the heat exhausting of cans the vacuum may not be proportional to the average temperature of the material at the time of sealing, but is determined largely by the temperature of the head space. Thus, a short exhaust results in a comparatively high vacuum if the sealing is done immediately. On the other hand, a long exhaust may be very ineffective if the sealing is delayed so that the head space cools.

(7) The vacuum developed in tin cans is generally below the theoretical, the causes contributing to the variation from theoretical values being the distortion of the can, the swelling of colloidal substances, and the liberation of gases during processing. Lower vacuums are obtained where long processing periods are used and the higher retort temperatures are employed.

(8) The resistance of the can to internal pressure is very much greater than its resistance to external pressure; hence, the vacuum and the pressure can not safely be made numerically equal when processing much above 100° C. In order to reduce the strain due to internal pressure during processing, the sealing temperature is made as high as is possible without danger of collapse of the can in handling when subsequently cooled to normal temperature. The strain upon the can during processing is found by subtracting the pressure in the retort from that in the can. When the pressure in the retort is released the strain upon the can is increased by an amount somewhat less than the pressure in the retort, owing to the cooling which occurs during the release and to the further distortion of the can. The greatest strain upon the can occurs at the time the pressure in the retort reaches zero. The strain due to internal pressure is greater the lower the sealing temperature and the higher the processing temperature.

(9) The experimental work herein reported indicates that for most vegetables the optimum temperature for the sealing of No. 2 cans is 80° to 85°, and for No. 3 cans 75° to 80° C. This would be different, obviously, for fruits and other substances having high acidity and where the processing temperatures are low.

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